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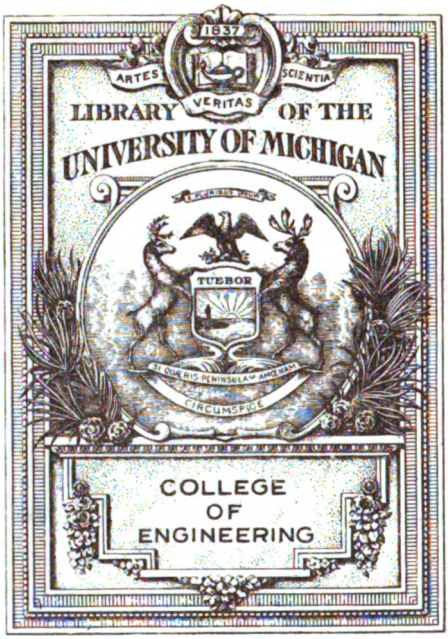

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SOCIETY OF AUTOMOTIVE ENGINEERS

INC.

PART I VOLUME XV 1920

Papers and Reports Presented at the Annual Society and Section Meetings

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ANNUAL MEETING

OF THE

SOCIETY OF AUTOMOTIVE ENGINEERS

INC.

NEW YORK CITY

JAN. 6-8, 1920

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MEETING OF THE STANDARDS COMMITTEE

The Standards Committee of the Society held a meeting on Jan. 6 to pass upon the subjects completed since the Semi-Annual Meeting at Ottawa Beach, Mich., in June 1919. B. B. Bachman, chairman of the Standards Committee, presided at the meeting which was in session from 10 o'clock in the morning until about 4 o'clock in the afternoon. Consideration was given to 48 recommendations submitted by the Ball and Roller Bearings, Electrical Equipment, Engine, Iron and Steel, Lighting, Miscellaneous, Motorcycle, Non-Ferrous Metals, Marine, Shaft Fittings, Stationary Engine and Lighting Plant, Tire and Rim, Tractor, and Truck Standards Divisions.

The reports of the Divisions as approved by the Standards Committee were reviewed and approved by the Council immediately following the Standards Committee meeting. The reports were duly presented at the Jan. 7 morning session of the Society Meeting and approved for submission to the voting members of the Society. The adopted reports are given on the following pages, together with the discussion at the meeting of the Standards Committee. [All S.A.E. Handbook page references are to the Handbook as of February 1920.]

Ball and Roller Bearings Division

(Report as adopted by the Society)

Annular Ball Bearings—Extra-Wide Type

The use of the extra-wide or double-row, as it is sometimes called, type of annular ball bearings is coming into prominence and the Ball and Roller Bearings Division desires to create a standard while the industry is in the formative period of development, but one company having manufactured this type of bearing extensively.

The Division has, therefore, recommended for adoption as S. A. E. Standard the following widths for the extra-wide type of annular ball bearings. The dimensions proposed conform to the widths for the present S. A. E. Standard for Roller Bearings given on pages 29d and 29e, S. A. E. Handbook, Vol. I, with the exception of No. 200 to 203, inclusive, of the Light Series, No. 300 to 303, inclusive, and 321 and 322 of the Medium Series, and all of

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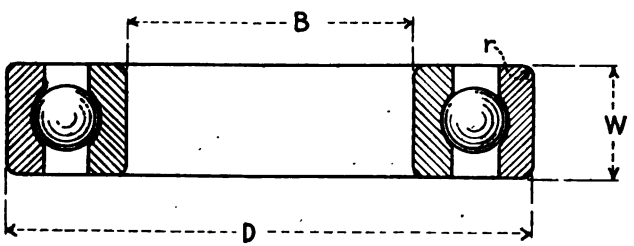
the Heavy Series for which there are no corresponding roller bearing standards.

WIDTHS OF EXTRA-WIDE TYPE ANNULAR BALL BEARINGS

Light Series		Medium Sizes		Heavy Series	
No:	Width, In.	No.	Width, In.	No.	Width, In.
200	1/2	300	3/4	....	.....
201	1/2	301	3/4	....	.....
202	1/2	302	3/4	....	.....
203	1/2	303	7/8	403	1 3/16
204	3/4	304	7/8	404	1 3/8
205	3/4	305	1	405	1 3/8
206	3/4	306	1 3/16	406	1 9/16
207	7/8	307	1 3/8	407	1 3/4
208	1	308	1 7/16	408	1 15/16
209	1	309	1 9/16	409	2 1/8
210	1	310	1 3/4	410	2 5/16
211	1 3/16	311	1 15/16	411	2 1/2
212	1 3/8	312	2 1/8	412	2 5/8
213	1 3/8	312	2 5/16	413	2 13/16
214	1 7/16	314	2 1/2	414	3 1/8
215	1 7/16	315	2 11/16	415	3 1/4
216	1 5/8	316	2 11/16	416	3 7/16
217	1 3/4	317	2 7/8	417	3 5/8
218	2	318	2 7/8	418	3 7/8
219	2 3/16	319	3 1/16	419	4 3/16
220	2 3/8	320	3 1/4	420	4 1/2
221	2 3/16	321	3 7/16	....	.....
222	2 3/4	322	3 1/8	....	.....

Annular Ball Bearings—Extra Large Type—Light Series

The Division has recommended for adoption as S. A. E. Standard the attendant series of extra large annular ball bearings. The Division is now working on tolerances for both the light and medium series.



Extra Large Type Light Series Annular Ball Bearings

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DIMENSIONS FOR LIGHT SERIES EXTRA LARGE TYPE BEARINGS

No.	B		D		W of Individual Rings		r Corner Radius	
	Mm.	In.	Mm.	In.	Mm.	In.	Mm.	In.
224	120	4.7244	215	8.4646	42	1.6535	3	0.12
226	130	5.1181	230	9.0551	46	1.8110	3	0.12
228	140	5.5118	250	9.8425	50	1.9685	3	0.12
230	150	5.9055	270	10.6299	54	2.1260	4	0.16
232	160	6.2992	290	11.4173	58	2.2835	4	0.16
234	170	6.6929	310	12.2047	62	2.4409	4	0.16
236	180	7.0866	330	12.9921	66	2.5984	4	0.16
238	190	7.4803	350	13.7795	70	2.7559	4	0.16
240	200	7.8740	370	14.5669	74	2.9134	5	0.20
242	210	8.2677	390	15.3543	78	3.0709	5	0.20

NOTE.—For temperature of measurement and definition of eccentricity, see page 29cc, S. A. E. Handbook, Vol. I.

TOLERANCES FOR LIGHT SERIES

Bore	+0.0002, —0.0006 in.
Outside diameter	+0.0000, —0.0012 in.
Width of individual rings	+0.0000, —0.0050 in.
Eccentricity:	
Inner race	0.0012 in.
Outer race	0.0018 in.

Annular Ball Bearings—Separable Type

The standard for the separable or open type of annular ball bearings accepted by the Society in April, 1919, page 29ca, S. A. E. Handbook, Vol. I, did not include tolerances. The Division has recommended for adoption as S. A. E. Standard the following inch tolerances for the annular ball bearings of the separable type:

Bore	+ 0.0000, — 0.0005 in.
Outside diameter	+ 0.0005, — 0.0000 in.
Eccentricity	
Inner race	0.0006 in.
Outer race	0.0012 in.

Annular Ball Bearings—Extra Small Type

The standard for the extra small type of annular ball bearings accepted by the Society in April, 1919, page 29cb, S. A. E. Handbook, Vol. I, did not include tolerances. The Division has recommended for adoption as S. A. E. Standard the following inch tolerances for annular ball bearings of the extra small type:

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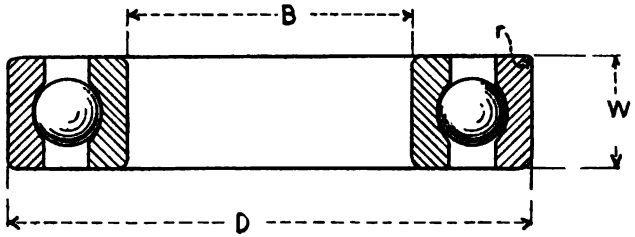
Bore	+ 0.0002, — 0.0004 in.
Outside diameter	+ 0.0000, — 0.0005 in.
Width of individual rings	+ 0.0000, — 0.0050 in.
Eccentricity	
Inner race	0.0006 in.
Outer race	0.0012 in.

Annular Ball Bearings—Extra Large Type—Medium Series



DIMENSIONS FOR MEDIUM SERIES EXTRA LARGE TYPE BEARINGS

No.	B		D		W of Individual Rings		r Corner Radius	
	Mm.	In.	Mm.	In.	Mm.	In.	Mm.	In.
324	120	4.7244	260	10.2362	55	2.1654	4	0.16
326	130	5.1181	280	11.0236	59	2.3228	4	0.16
328	140	5.5118	300	11.8110	63	2.4803	4	0.16
330	150	5.9055	320	12.5984	67	2.6378	4	0.16
332	160	6.2992	340	13.3858	71	2.7953	5	0.20
334	170	6.6929	360	14.1732	75	2.9528	5	0.20
336	180	7.0866	380	14.9606	79	3.1102	5	0.20
338	190	7.4803	400	15.7480	83	3.2677	5	0.20
340	200	7.8740	420	16.5354	87	3.4252	5	0.20
342	210	8.2677	440	17.3228	89	3.5039	5	0.20

NOTE.—For temperature of measurement and definition of eccentricity, see page 29cc, S. A. E. Handbook, Vol. I.

TOLERANCES FOR MEDIUM SERIES

Bore	+0.0002, —0.0006 in.
Outside diameter	+0.0000, —0.0012 in.
Width of individual rings	+0.0000, —0.0050 in.
Eccentricity:	
Inner race	0.0012 in.
Outer race	0.0018 in.

Corner Radii Tolerances

Trouble has been experienced, particularly in aeronautical work, owing to the rounding of the edges of the

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outer race not being a true quarter circle. The Division has therefore recommended that all corner radii in present and future standards for ball and roller bearings be specified as minimum radii.

Electrical Equipment Division

(Report as adopted by the Society)

Bracket Mounting for Generators

The Division has recommended that the present S. A. E. Standard for Bracket Mounting for Generators, page 36xc, S. A. E. Handbook, Vol. I, be revised so that the thread for the shaft-end will be 7/16 in.-20 S. A. E. instead of 7/16 in.-14 U. S. S., as the S. A. E. Standard thread is used in present practice instead of the U. S. Standard.

Flange Mounting for Generators

The Division has recommended that the present S. A. E. Standard for Flange Mounting for Generators, page 36c, S. A. E. Handbook, Vol. I, be extended to specify the shaft-end as ½ in.-20 S. A. E. instead of ½ in. as at present.

Engine Division

(Report as adopted by the Society)

Tractor Flywheel Housings

When the tractor engine and transmission case are used as a self-supported unit it is often desired to use larger capscrews than those given in the present standard. The Division has therefore recommended that a note substantially as follows be included in the present standard given on pages 31 and 31a, S. A. E. Handbook, Vol. I.

> When it is desired to use ½ in.-13 in place of ⅜ in.-16 U. S. Standard capscrews, they shall be located on the standard bolt circle, the flange inside diameter remaining the same, but the outside diameter of the transmission case flange may be increased by ½ in.
>
> When the outside diameter of the transmission case flange is not finished, as when channel iron supporting pads or brackets are cast over the edge of the flange, the outside diameter of the transmission case flange is increased ½ in.

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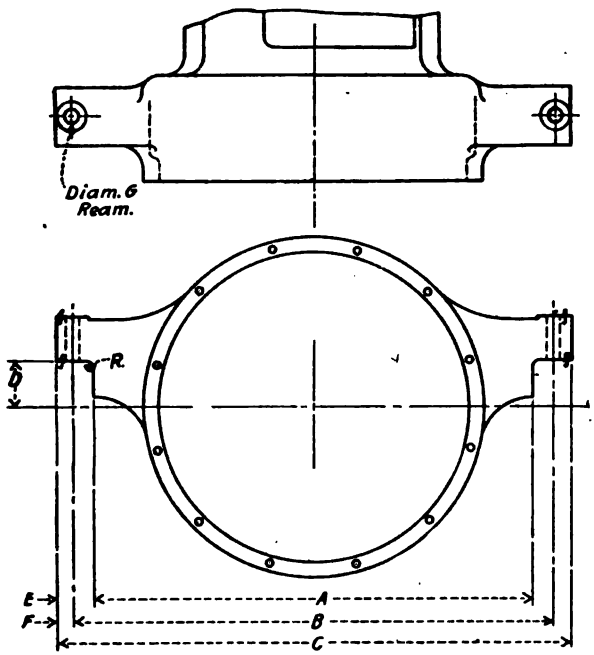
over the outside diameter of the standard finished flange. The inside diameter and the bolt circle are to be the same in either case.

Engine Support Arms



DIMENSIONS FOR TRUCK AND TRACTOR ENGINE SUPPORT ARMS

No.	A	B	C	D	E	F	G	R Max	Practice
1	23½	26⅝	28⅝	2	2⅝	1	0.750	7/16	Truck and tractor
2	23½	24½	25⅝	2½	1 11/16	⅝	0.625	⅜	Truck
2T	20	21⅝	23½	3	1⅝	⅝	0.625	¼	Truck and tractor

In tractor practice the support arms are generally bolted to the top of the side member and in truck practice to a sub-frame or to brackets mounted inside the side member.
Engine support arm No. 1 is intended for use on flywheel housing No. 1, No. 2 on flywheel housings No. 2, 3 and 4, and No. 2T on flywheel housing No. 2.

In preparing the following proposal, data and suggestions were obtained from tractor and tractor engine manufacturers and carefully considered by a Subdivision

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composed of engine and tractor transmission manufacturers. In reference to the recommendation for the No. 2T size it was considered advisable to maintain 20 in. between the side-rails because this dimension is extensively used in present practice and any increase over 20 in. would materially affect the turning radius of the tractor, which is one of the most important factors in tractor design.

As the present S. A. E. Recommended Practice for truck engine support arms, page 31b, S. A. E. Handbook, Vol. I, is now well established, the Division recommends that it be changed to S. A. E. Standard.

The proposed standard for engine support arms for the No. 1 and 2T flywheel housings for tractor practice is given elsewhere herein, together with the present recommended practice for the No. 1 and 2 sizes for truck practice.

Crankshaft Grinding Wheels

Data obtained by the Subdivision appointed to consider this subject showed that with sixty-four companies representing the passenger car, commercial vehicle and tractor industries there are twenty-nine widths of crankshaft pins and seven radii in common use. It is felt that the adoption of a standard will enable abrasive wheel manufacturers to reduce the number of stock wheel sizes materially and permit quicker delivery than when wheels are made to purchasers' specifications. The proposed standard will also indicate a uniform means for specifying wheel widths, as it is stated that there is at present considerable misunderstanding regarding the extra width allowed on new wheels for dressing purposes.

The intention of the Subdivision was to standardize the crankshaft pin lengths, but the Division believes that the results desired will be accomplished better by specifying the wheel widths as now recommended for adoption.

WIDTHS AND CORNER RADII OF CRANKSHAFT GRINDING WHEELS

Nominal Widths, In.	Radii of Edges, In.
1 1/2, 1 5/8, 1 3/4, 1 7/8, 2, 2 1/8, 2 1/4, 2 3/8, 2 1/2, 2 5/8, 3, 3 1/4, 3 1/2, 3 3/4, 4	3/32 max.

This specification applies only to unfinished grinding wheels for crankshafts. Wheels are to be ordered by the purchaser to the specified nominal widths. The wheel manufacturer allows 0.029 in. additional to widths for truing. Radii of edges are specified as maximum to allow for dressing wheels to crank-pin radii.

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THE DISCUSSION

H. M. CRANE:—With regard to the radius of the edge of the grinding wheels, which is given as 3/32 in. maximum, I assume that is done with the understanding that the crankshaft manufacturer will modify that radius. That dimension, 3/32 in., is of course, too small a radius to use for crankshaft fillets.

R. S. BURNETT:—This radius applies to the unfinished wheel so that the manufacturer can dress it to whatever radius he wants for grinding the crankshaft.

MR. CRANE:—The footnote to the table regarding the fact that the grinding wheel manufacturers allow 0.029 in. in addition on the width for truing wheels, should be amplified to explain the reason for the 3/32 in. maximum radius, to make it clear that this also is specified to allow for truing and for reaching a radius that is properly proportioned to the crank bearing itself.

ALBERT TURNER:—Regarding the widths for grinding wheels I believe that the gradation is too fine as proposed and that the ⅛-in. sizes should be omitted; that is, the series should progress in steps of ¼ in. instead of ⅛ in. The wheel manufacturers have standardized to a considerable extent and make wheels in ¼-in. steps. When a wheel is ordered in ⅛-in. size it is necessary to dress it down from the next larger size, causing extra expense. If the widths were in even ¼-in. steps the wheels could be kept in stock and there would not be the additional expense of truing them down. This would also reduce the number of sizes in the table from fifteen to twelve, which I think would be ample to cover the necessary range.

The 3/32-in. radius should be specified as a minimum instead of a maximum. The wheels, when they are first made ready for shipment, are square cornered. The purpose of the radius on the corner is to make the wheel stand up in use. If the radius is too small on the corner it will break down in use, but if it is made of ample size it will stand up much longer. About ⅛ in. should be the minimum radius, but as a little variation should be allowed, a 3/32-in. minimum radius will probably be satisfactory.

MR. BURNETT:—The original proposal of the Subdivision which prepared this report included the ⅛-in. progression of sizes as shown in the report. It was not believed wise to take out the ⅛-in. step from the nar-

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rower sizes as this would limit the number of widths too greatly. The preliminary recommendation applied to the crankshaft pins, however, rather than to the wheels. The radius originally specified by the Subdivision applied to the crankshaft pins and was ⅛ in. up to a 3-in. pin diameter and 3/16 in. for the larger diameters. Members of the Engine Division felt, however, that the grinding wheel widths should be specified so that the crankshaft or engine builder could grind the crank-pins to any length desired, and that the radius should be a maximum to leave enough material for the user to dress the edge of the wheel to the radius of the crank-pin fillet. The dressing of the wheel is, of course, left to the user and it is intended that the dimensions in the proposal shall apply to the rough wheel as purchased from the wheel manufacturer.

CHAIRMAN B. B. BACHMAN:—With regard to the specifying of the radius there is probably a tendency to be a trifle confused as to whether we are speaking of the product or the tool. If we are speaking of the product, the wording should be minimum; if we are speaking of the tool, it should be maximum, because what is wanted is a wheel that will have sufficient material on the edge to allow for dressing down to a proper radius in proportion to the pin.

Engine Testing Forms

As the present S. A. E. Standard for Engine Testing Forms is satisfactory for kerosene fuel engine testing, the Division has recommended that a note be added to the forms stating that they are intended for engines using either gasoline or kerosene fuel.

IRON AND STEEL DIVISION

(Report as adopted by the Society)

Malleable Iron Castings

Malleable iron castings are being used to a large extent in the automotive industry, and the Division has therefore recommended that the A. S. T. M. Specification No. A 47-19 for malleable castings be adopted as S. A. E. Standard.

In 1914 the original malleable castings specification adopted by the Society was withdrawn, as it was based on chemical analysis and was not practicable. The present

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proposal applies to the physical characteristics of malleable castings, which is considered the best method of controlling the quality of this product.

Malleable Iron Castings[1]

Material Covered These specifications cover malleable castings for general automotive purposes.

Process The castings shall be produced by either the air-furnace, open-hearth, or electric-furnace process.

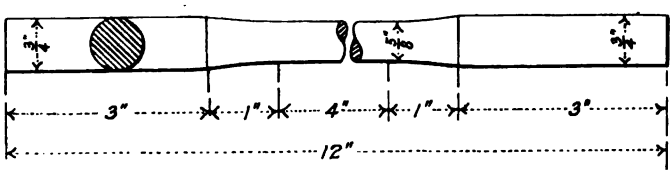
Tension Tests The tension test-specimens specified shall conform to the following minimum requirements as to tensile properties:

Tensile strength, lb. per sq. in.	45,000
Elongation in 2 in., per cent	7.5

Special Tests All castings, if of sufficient size, shall have cast thereon test-lugs of a size proportional to the thickness of the casting, but not exceeding ⅝ by ¾ in. in cross-section. On castings which are 24 in. or over in length, a test-lug shall be cast near each end. These test-lugs shall be attached to the casting at such a point that they will not interfere with the assembling of the castings, and may be broken off by the inspector.

If the purchaser or his representative so desires, a casting may be tested to destruction. Such a casting shall show good, tough malleable iron.

Tension Test-Specimens[2] Tension test-specimens shall be of the form and dimensions shown. Specimens whose mean diameter at the smallest section is less than 19/32 in. will not be accepted for test.



MALLEABLE IRON TENSION TEST-SPECIMEN

A set of three tension test-specimens shall be cast from each melt, without chills, using heavy risers of sufficient height to secure sound bars. The specimens shall be suitably marked for identification with the

[1]This specification conforms with Specification No. A47-19 of the American Society for Testing Materials.

[2]Test-specimens are not machined.

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melt. Each set of specimens so cast shall be placed in some one oven containing castings to be annealed.

Number of Tests After annealing, three tension test-specimens shall be selected by the inspector as representing the castings in the oven from which these specimens are taken.

If the first specimen conforms to the specified requirements, or if, in the event of failure of the first specimen, the second and third specimens conform to the requirements, the castings in that oven shall be accepted, except that any casting may be rejected if its test-lug shows that it has not been properly annealed. If either the second or third specimen fails to conform to the requirements, the entire contents of that oven shall be rejected.

Reannealing Any castings rejected for insufficient annealing may be reannealed once. The reannealed castings shall be inspected and if the remaining test-lugs, or castings broken as specimens, show the castings to be thoroughly annealed, they shall be accepted; if not, they shall be finally rejected.

Workmanship The castings shall conform substantially to the patterns or drawings furnished by the purchaser, and also to gages which may be specified in individual cases. The castings shall be made in a workmanlike manner. A variation of ⅛ in. per ft. will be permitted.

Finish The castings shall be free from injurious defects.

Marking The manufacturer's identification mark and the pattern numbers assigned by the purchaser shall be cast on all castings of sufficient size, in such positions that they will not interfere with the service of the castings.

Inspection The inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the castings ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the castings are being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

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The manufacturer shall be required to keep a record of each melt from which castings are produced, showing tensile strength and elongation of test-specimens cast from such melts. These records shall be available and shown to the inspector whenever required.

Rejection Castings which show injurious defects subsequent to their acceptance at the manufacturer's works may be rejected, and, if rejected, shall be replaced by the manufacturer free of cost to the purchaser.

THE DISCUSSION

F. P. GILLIGAN:—The malleable iron specification is recommended for adoption in response to a number of specific requests from members, and in view of the fact that the American Society for Testing Materials had developed the best type of malleable iron specifications that we knew of, the members of the Division felt that it would be desirable to adopt it without change.

CHAIRMAN B. B. BACHMAN:—There is a question of policy which should be considered in connection with this matter. The question has been raised as to whether it is the function of the S. A. E. to deal with matters having to do with the testing of materials. The proposal deals principally with the properties which shall be required and with the methods for determining these properties.

H. M. CRANE:—I feel that it would be wise to publish this proposal as general information and as a specification of the American Society for Testing Materials, as it involves the relations between purchaser and seller to a large extent. It brings in questions of inspection, etc., which I do not think properly belong in this Society's Standards as such. It is, however, a very valuable specification to have in the Handbook as to what has been worked out in a practical way toward determining whether malleable castings are satisfactory. It is generally acknowledged that it is very difficult to specify what the castings should be and a specification such as proposed will serve as a valuable guide to engineers. However, if the American Society for Testing Materials should alter its specifications we would have to do likewise.

MR. GILLIGAN:—The point in connection with malleable iron is that chemical composition alone is of no value. The maker must, of course, work within certain limits, but the castings may have the required composition and still lack the physical properties and other characteristics desired in malleable iron castings. The only way to control

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the quality of malleable iron is by making fracture tests, etc., leaving the composition of the castings to the maker. The Society had formerly a specification that was based primarily on composition, but it failed to attain its purpose. The proposed specification has been developed by specialists and represents the best American practice.

H. S. PIERCE:—It appears to me that the specification proposed is a broad generality. Foundries making many malleable castings soon learn that castings for various purposes require different degrees of hardness and elongation. Malleable iron is not a definite substance; it can be made to suit conditions.

H. J. STAGG:—I think that the main point to be brought out here is that sometimes a chemical specification means absolutely nothing. The physical specification is all-important. If the Society adopts a malleable iron specification, I am strongly in favor of adopting a method of determining the physical properties of the iron.

MR. CRANE:—The conditions applying to malleable iron are the same as apply to cast iron and to the method of making piston-rings. The specification of chemical analysis alone is an absolutely impossible method of controlling the quality of castings.

G. L. NORRIS:—I believe that it should be the policy of the Society to have its specifications conform with those of the American Society for Testing Materials in respect to the methods of testing and determining physical properties.

MR. CRANE:—With respect to the test-specimen in this specification, is it to be understood that the bars are not machined?

JAMES S. MACGREGOR:—It is important in a specification of this kind to state the condition of the test-specimen. Specimens of malleable cast iron tested as cast and malleabilized yield very different results from those obtained if the specimens are machined before testing.

MR. GILLIGAN:—It is not customary to machine these test-specimens. A footnote to this effect can be included in the specification.

High-Chromium Steel

In line with the Division policy of publishing in THE JOURNAL and the S. A. E. Handbook information about all types and uses of new steels coming before the industry, a Subdivision was appointed to review all available data in reference to high-chromium steel. The follow-

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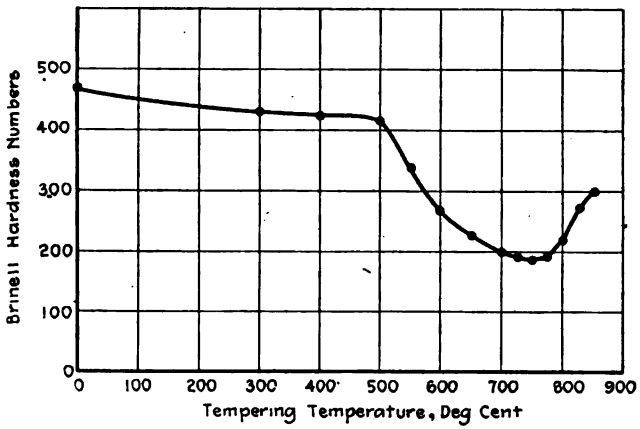

RELATION BETWEEN THE TEMPERING TEMPERATURES AND THE BRINELL HARDNESS NUMBERS OF HIGH-CHROMIUM STEEL

ing report has been accepted by the Division and published in THE JOURNAL.[3]

High-chromium, or what is called stainless steel containing from 11 to 14 per cent chromium, was originally developed for cutlery purposes, but has in the past few years been used to a considerable extent for exhaust valves in airplane engines because of its resistance to oxidation or scaling at high temperatures.

	Per cent
Carbon	0.20 to 0.400
Manganese, not to exceed	0.500
Phosphorus, not to exceed	0.035
Sulphur, not to exceed	0.035
Chromium,	11.50 to 14.000
Silicon, not to exceed	0.300

Forging The steel should be heated slowly and forged at a temperature above 1750 deg. fahr., preferably between 1800 and 2200 deg. fahr. If forged at temperatures between 1650 and 1750 deg. fahr. there is considerable danger of rupturing the steel because of its hardness at red heat. Owing to the air-hardening property of the steel, the drop-forgings should be trimmed while hot. Thin forgings should be reheated to redness before trimming, as otherwise they are liable to crack.

[3]See THE JOURNAL, September 1919, p. 262.

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Heat-Treatment Forgings will be hard if they are allowed to cool in air. This hardness varies over a range of from 250 to 500 Brinell, depending on the original forging temperature.

Annealing This can be done by heating to temperatures ranging from 1290 to 1380 deg. fahr. and cooling in air or quenching in water or oil. After this treatment the forgings will have a hardness of about 200 Brinell and a tensile strength of 100,000 to 112,000 lb. per sq. in. If softer forgings are desired they can be heated to a temperature of from 1560 to 1650 deg. fahr. and cooled very slowly. Although softer the forgings will not machine as smoothly as when annealed at the lower temperature.

Hardening The forgings can be hardened by cooling in still air or quenching in oil or water from a temperature between 1650 and 1750 deg. fahr.

Valves These have generally been made to the following specification of physical properties:

Yield point, lb. per sq. in.	70,000
Tensile strength, lb. per sq. in.	90,000
Elongation in 2 in., per cent	18
Reduction of area, per cent	50

The usual heat-treatment is to quench in oil from 1650 deg. fahr. and temper or draw at 1100 to 1200 deg. fahr. One valve manufacturer stated that valves of this steel are hardened by heating the previously annealed valves to 1650 deg. fahr. and cooling in still air. This treatment gives a scleroscope hardness of about 50.

Cold-Working This steel can be drawn into wire, rolled into sheets and strips and drawn into seamless tubes.

Corrosion This steel like any other steel when distorted by cold working is more sensitive to corrosion and will rust. Rough cut surfaces will rust. Surfaces finished with a fine cut are less liable to rust. Ground and polished surfaces are practically immune to rust.

Scaling Comparative resistance to scaling or oxidation at high temperatures is shown in the accompanying chart.

Physical Properties The physical properties do not vary greatly when the carbon is within the range of

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COMPARISON OF PHYSICAL PROPERTIES FOR HIGH-CHROMIUM STEELS OF DIFFERENT CARBON CONTENT

	C 0.20 Mn 0.45 Cr 12.56	C 0.27 Mn 0.50 Cr 12.24	C 0.50 Cr 14.84
Quenched in oil from deg. fahr.	1,600	1,600	1,650
Tempered at deg. fahr.	1,160	1,080	1,100
Yield point, lb. per sq. in.	78,300	75,000	91,615
Tensile strength, lb. per sq. in.	104,600	104,250	123,648
Elongation in 2 in., per cent	25.000	23.500	14.500
Reduction of area, per cent	52.500	51.400	33.500

COMPARISON OF PHYSICAL PROPERTIES BETWEEN AIR, OIL AND WATER-HARDENED STEEL HAVING CHEMICAL ANALYSIS IN PERCENTAGE OF

Carbon	0.240
Manganese	0.300
Phosphorus	0.035
Sulphur	0.035
Chromium	12.850
Silicon	0.200

Hardening Medium	Hardened from. deg. fahr.	Tempered at, deg. fahr.	Elastic Limit, lb. per sq. in.	Tensile Strength lb. per. sq. in.	Elongation in 2 In. per cent	Reduction of Area, per cent
Air	1,650	930	158,815	192,415	13.0	40.5
		1,100	99,680	120,065	21.0	59.2
		1,300	70,785	101,250	26.0	64.6
		1,380	66,080	98,335	28.0	63.6
		1,470	70,785	96,990	27.0	64.7
Oil	1,650	930	163,070	202,730	8.0	18.2
		1,100	88,255	116,480	20.0	56.9
		1,300	77,950	105,505	25.5	63.8
		1,380	88,255	98,785	27.0	66.3
Water	1,650	930	158,815	202,050	12.0	34.2
		1,100	90,270	120,735	22.0	59.8
		1,300	66,080	102,590	25.8	64.8
		1,380	67,200	97,890	27.0	65.2

composition given, or when the steel is hardened and tempered in air, oil, or water.

Applications In addition to use in valves this steel should prove very satisfactory for shafting for water-pumps and other automobile parts subject to objectionable corrosion.

THE DISCUSSION

CHAIRMAN B. B. BACHMAN:—This proposal is presented for consideration as general information only. The reason for this is that it is claimed that certain patent rights apply to this particular steel, and in accordance with our procedure we are not adopting as standard

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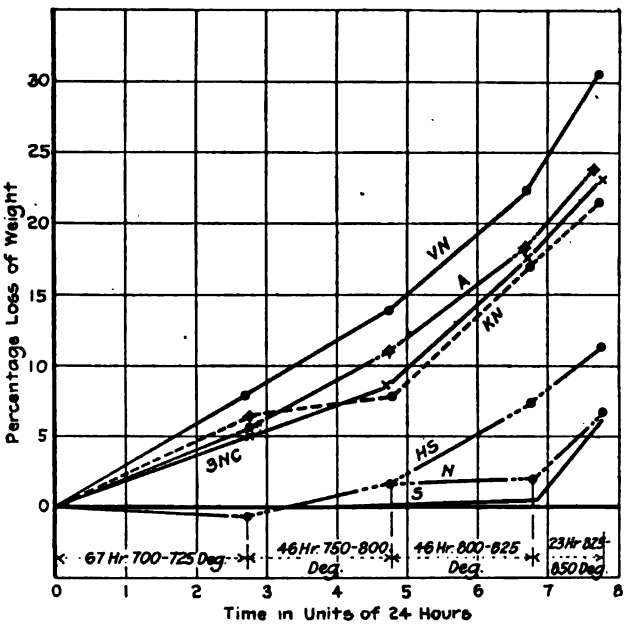

RESULTS OF SCALING TESTS OF VARIOUS STEELS

S, high-chromium steel; HS, high-speed steel; KN, 3NS, nickel chromium steel; N, 25 per cent nickel steel; N, 5 per cent nickel steel; A, 0.30 per cent carbon steel.
Specimens were heated at the temperatures stated and weighed every 24 hr. after removing the scale.
Temperatures in degrees centigrade.

or recommended practice anything claimed to be of a proprietary nature.

Nickel Steel

As 5 per cent nickel steel is widely used for case-hardened parts, the Division has recommended for adoption as S. A. E. Standard the following composition for 5 per cent nickel steel to be known as S. A. E. Specification No. 2512.

Specification No. 2512

	Per cent
Carbon, not to exceed	0.170
Manganese	0.30 to 0.600
Sulphur, not to exceed	0.045
Phosphorus, not to exceed	0.040
Nickel	4.50 to 5.250

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Tungsten Steel

The Iron and Steel Division has recommended for adoption as S. A. E. Standard the following composition for low-tungsten steel, to be known as S. A. E. Specification No. 7260. Low-tungsten steel is more widely used for both inlet and exhaust valves than high-tungsten steel. The composition proposed conforms to Specification No. W60b of the Bureau of Aircraft Production.

Specification No. 7260

	Per cent
Carbon	0.50 to 0.700
Manganese, not to exceed	0.300
Phosphorus, not to exceed	0.035
Sulphur, not to exceed	0.035
Chromium	0.50 to 1.000
Tungsten	1.50 to 2.000

LIGHTING DIVISION

(*Report as adopted by the Society*)

Side-Lamp Glasses

DIMENSIONS FOR SIDE-LAMP GLASSES

Outside Diameter of Lens		Minimum Light Opening in Door	
Nominal Diameter	Tolerances	Nominal Diameter	Tolerances
2	+0, −1/32	1⅝	+0, −1/32
2⅛	+0, −1/32	2⅛	+0, −1/32
*3	+0, −1/32	2½	+0, −1/32
5	±1/32	4	±1/32
†6	±1/32	5	±1/32
7	±1/32	6	±1/32

Dimensions in inches.
*Also tail-lamp glass.
†Also spot-lamp glass.
Thickness of bevel edge for all sizes is ⅛ in., plus 1/32, minus 0. This is commonly known as double-thick American glass.
This standard is to become fully operative July 1, 1921.

The Lighting Division has recommended for adoption as S. A. E. Standard the following series of side-lamp glass dimensions. The present standard tail-lamp glass is 3 in. in diameter with tolerances of plus 1/32 in., minus 1/64 in. The recommendation changes these tolerances to conform with those recommended for head-lamp, side-lamp and spot-lamp glasses. The recommendation, together with the present standard for head-lamp glasses,

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is intended for automobile electric and oil-lamp glasses including types such as semaphore, beehive and prism.

Head-Lamp Illumination

The present S. A. E. Recommended Practice for Head-Lamp Illumination states that no portion of the direct reflected beam cone of light shall rise about 42 in. As the direct reflected beam cone of light cannot always be satisfactorily defined and as a certain amount of light should be permitted above 42 in., it is believed that the actual glare and illumination candlepower values which should obtain at certain parts of a screen when placed 100 ft. in front and at right angles to the axis of the head-lamps should be specified. Measurements of the illumination produced can be made easily and accurately by means of a portable foot-candle meter and it is therefore very simple to determine whether or not the head-lamps are properly adjusted to comply with any requirements.

The present Recommended Practice, adopted by the Society in 1916 and revised in 1917 and in 1918, is as follows:

> The head-lamps shall be arranged so that no portion of the direct reflected beam cone of light when measured 75 ft. ahead of the head-lamps shall rise above 42 in. from the level surface of the road on which the vehicle stands under any conditions of loading; nor shall any portion of the direct reflected beam cone of light rise beyond the 75-ft. distance more than 12 in. above the center of the head-lamps.

The Lighting Division, in cooperation with the Committee on Automobile Headlighting Specifications of the Illuminating Engineering Society, has done considerable research work on head-lamp illumination and has recommended that the present S. A. E. Recommended Practice be revised to conform to the following:

> The head-lamps shall be arranged so that under normal conditions of loading
>
> The light produced at a distance of 100 ft. directly ahead of the head-lamps and at a height of 60 in. or more above the level surface on which the automotive vehicle stands shall not exceed 2400 apparent cp.
>
> The light produced 100 ft. ahead of the vehicle

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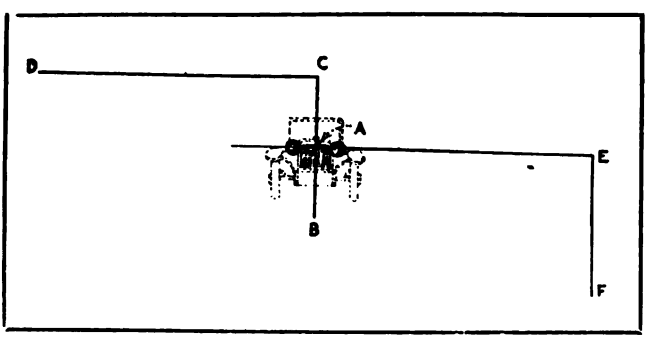
and 7 ft. or more to the left of its axis and at a height of 60 in. or more above the level surface on which the vehicle stands shall not exceed 800 apparent cp.

This recommendation is based on the results of a series of tests made in 1918 and 1919. The first tests were made to indicate how much light is necessary to reveal a man in dark clothes 250 ft. in front of a car and how much light the driver can tolerate without feeling that the glare is objectionable and unsafe to drive against. Head-lamps were placed on a level concrete road in relatively the same positions that they would be on two cars preparing to pass, the distance between the two pairs of head-lamps being 100 ft.

The electrical and photometric equipment was such that the intensity of the light for either pair of head-lamps could be varied by the observer and his opinions of glare and illumination recorded. The procedure followed was to have the observer increase the illumination of his own head-lamps until he felt that the illumination was adequate to reveal a man at 150 and then at 250 ft. in front of the head-lamps. Then with these head-lamps set at this recorded intensity the opposing head-lamps were turned on and the illumination increased until in the observer's opinion the glare was at a maximum for safe and convenient driving.



POINTS USED FOR SPECIFYING CANDLEPOWER VALUES

Location of points is as follows: *A* is level with center of head-lamps and 100 ft. ahead of vehicle, *B* is 1 deg. or 21 in. below *A*, *C* is 1 deg. or 21 in. above *A*, *D* is 4 deg. or 7 ft. to the left of *C* as observed from the vehicle, *E* is 4 deg. or 7 ft. to the right of *A*, and *F* is 2 deg. or 42 in. below *E*. The passenger car is shown in the illustration only to indicate the location of point *A* with respect to the head-lamps.

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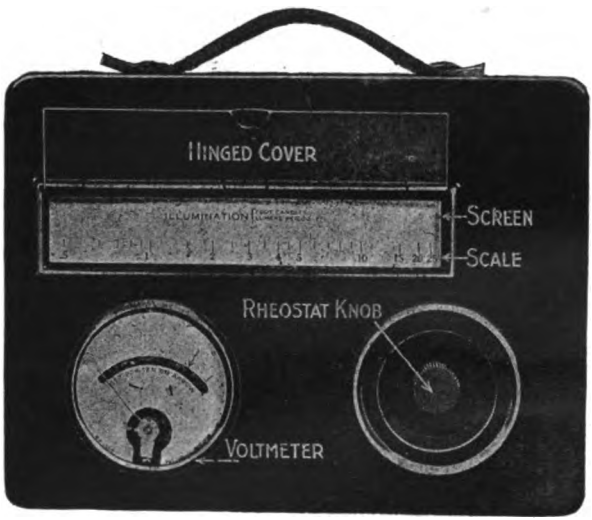
Subsequent tests were made with automobiles equipped with head-lamps adjusted to give approximately the values deduced from the observations made in the first tests by the fifty observers. It was decided as a result of these tests that it was necessary to have approximately 4800 apparent cp. to obtain satisfactory road illumination at 200 ft. and that dangerous glare would be experienced



TYPE OF PORTABLE FOOT-CANDLE METER USED

if the illumination at 1 deg. above the horizontal exceeded 2400 apparent cp. and the illumination at 1 deg. above and 4 deg. to the left of the axis of the car exceeded 800 apparent cp.

Tests were recently conducted with head-lamps adjusted to give the following illumination and glare candlepower values at 100 ft. ahead of the head-lamps and for the points shown in the drawing on page 21. The candlepower values were determined by the foot-candle meter shown.

At some point between *A* and *B*, 4800 apparent cp.
At point *C*, 2400 apparent cp.
At point *D*, 800 apparent cp.
At some point between *E* and *F*, 1200 apparent cp.

The equipment consisted of three cars equipped with special head-lamps, lenses, storage batteries, voltmeters

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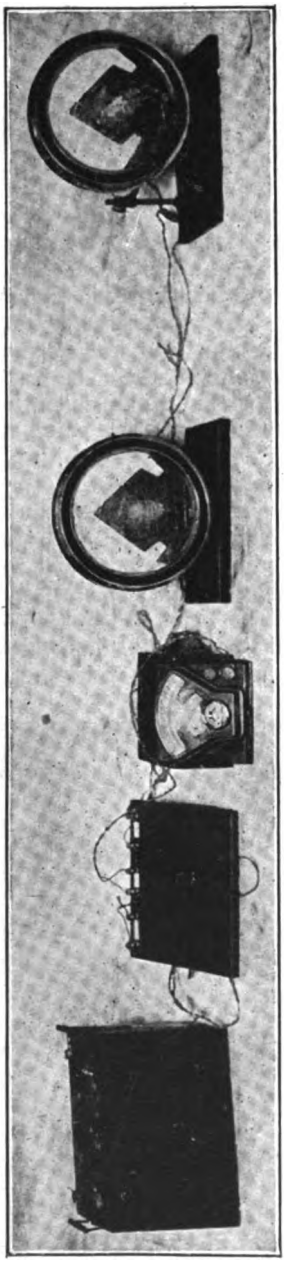

EQUIPMENT USED ON EACH TEST PASSENGER CAR.

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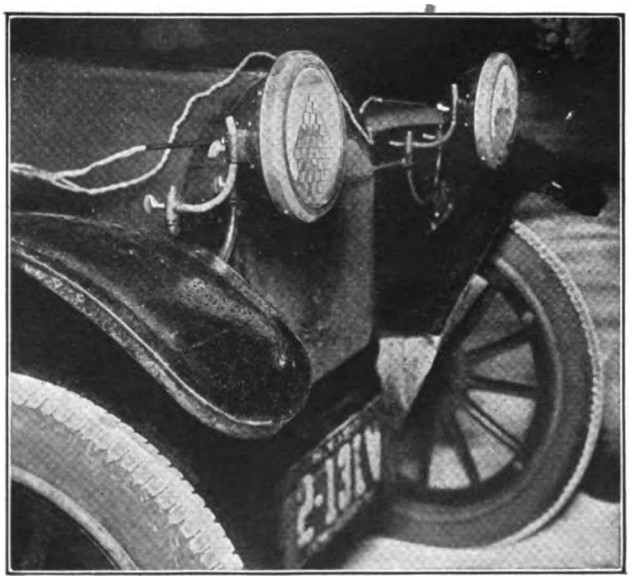
and rheostats. The equipment for each car was as shown on page 23. The cars were operated on a dark night at equal intervals on a level macadam road recently surfaced, which was selected on account of the absence of street and house lights. After 20-min. runs observers were requested to give their opinions as to the glare produced by the head-lamps of oncoming cars and the adequacy of the illumination produced on the road by the head-lamps of the car in which they were riding.

The result of the tests showed that ten observers were of the opinion that the glare was excessive, ten that it was not excessive, and six that it was the most that should be permitted. The analysis of the observations, however, indicated that the glare value was satisfactory as a maximum.

The observations also indicated that the illumination of 4800 apparent cp. as a minimum at some point between *A* and *B* was satisfactory as a legal requirement, but that a higher value should be specified for recommended practice. It is thought that an illumination of 10,000 cp. at some point between *A* and *B* would be more satisfactory and that the light produced at 4 deg. on either side of the axis of the vehicle and between the



METHOD OF MOUNTING SPECIAL HEAD-LAMPS.

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level of the head-lamps and 2 deg. below this level should be increased to at least 2400 cp.

The Division in cooperation with the Illuminating Engineering Society's Committee plans to run additional tests with head-lamps calibrated to give these proposed candlepower values.

THE DISCUSSION

H. M. CRANE:—The Lighting Division in cooperation with the Illuminating Engineering Society has done much toward working out an arrangement that can be readily controlled and which will give the best possible driving light combined with the least possible amount of dangerous glare. There are undoubtedly patented head-lamp glasses which would do the work perfectly well if applied to the car properly, but we frequently see cars with various types of lenses which have worked out of their proper position, and instead of lighting the road they throw a strong light in the eyes of the oncoming driver. One object of the committee is to develop, if possible, some type of control that can be readily understood by the average owner and which can be expected to continue to perform the desired service without continuous attention.

W. A. MCKAY:—The former Recommended Practice of the Society was that the head-lamp should be arranged so that no portion of the direct reflected beam cone of light should rise above 42 in. from the surface of the road. As the direct reflected beam cone of light cannot always be satisfactorily defined and as a certain amount of light should be permitted above 42 in., it is believed that the actual glare and illumination candlepower values which should obtain at certain parts of a screen when placed 100 ft. in front of, and at right angles to, the axis of the head-lamps should be specified. Measurements of the illumination produced can be easily and accurately made by a portable foot-candle meter and it is therefore very simple to determine whether or not the head-lamps are properly adjusted to comply with any requirements. Formerly head-lamp specifications simply stated that certain conditions should not exist, usually that there should not be a certain glare. There was always difficulty in determining whether the head-lamps did produce dangerous glare. The proposed specifications have definite candlepower values so that the illumination can be measured with a portable foot-candle meter, making it possible for those who have to do with the enforcement

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of laws to find out definitely whether a head-lamp is adjusted in accordance with such a specification as the one proposed.

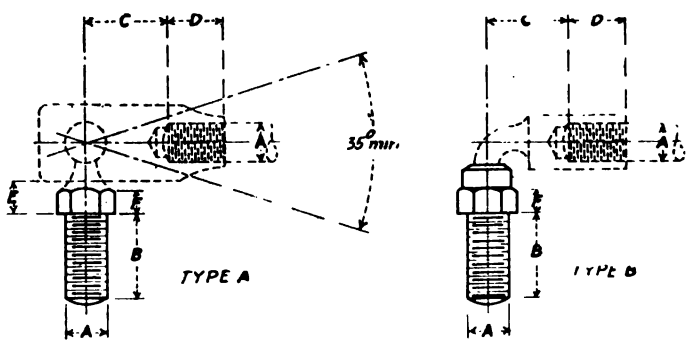
DR. C. H. SHARP:—The Committee on Automobile Headlighting Specifications of the Illuminating Engineering Society has given the matter of the proper limitation of headlight glare much consideration and has made many practical road tests for the purpose of establishing the values which are given in your report. Of course glare limitations can never be absolute, inasmuch as the limit of tolerable glare from an approaching car depends upon the road illumination produced by one's own lights. The figures given in the report, however, are based on reasonable values of road illumination. These figures were first promulgated in connection with the specifications for acceptability of headlighting devices under the New York State law, and were prepared by the Committee on Automobile Headlighting Specifications at the request of Secretary of State Hugo for that purpose. Since then they have entered into the regulations of the States of Connecticut, Pennsylvania and California. They therefore have already a very considerable degree of sanction on the part of the law-making and law-administrating authorities.

MISCELLANEOUS DIVISION

(Report as adopted by the Society)

Ball-and-Socket Joints

The Division has recommended for adoption as S. A. E. Standard the attendant dimensions for ball-and-socket



BALL-AND-SOCKET JOINTS

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joints. The tentative recommendation has been submitted to manufacturers and users and their criticism obtained. The proposed standard applies to the two most widely used types of ball-and-socket joints and the series of sizes proposed meets all general requirements for spark and throttle control.

DIMENSIONS FOR BALL-AND-SOCKET JOINTS

A	Hex Min.	B	C	D	[5]E	[6]F Min.
No. 5-40	1/4	9/32	1/1	1/4	7/.2	3/32
No. 8-32	1/4	11/32	11/12	5/16	7/32	7/64
No. 10-32	5/16	13/32	13/:2	/8	1/4	1/
No. 12-32	5/8	15/32	7/16	3/	1/4	9/61
1/4-28	3/8	9/16	1/2	/:3	9/.4	5/32
5/16-24	7/16	23/32	5/8	9/16	9/32	3/16
3/8-24	9/16	7/8	3/4	11/16	5/16	7/32
7/16-20	5/8	1	7/8	13/16	3/8	1/4
1/2-20	3/4	1 1/8	1	1 1/16	7/16	9/32

[5]Minimum wrench clearance.
[6]F=1/2 A+1/32.
Dimensions in inches.
All threads are S. A. E.

THE DISCUSSION

E. H. EHRMAN:—The standardization of ball-and-socket joints has been under consideration by the Miscellaneous Division for approximately 2 years and the members believe that the proposed specification will cover practically all requirements in a satisfactory manner. There is one point that I would like to explain. The National Screw Thread Commission plans to discard all fractional sizes below ¼ in., so the Division recommends that 7/32 in. be expressed as No. 12, since it is almost identical with it. The pitch of 32 threads per inch is pretty well established in the product of one manufacturer of ball-and-socket joints and it is claimed that the sale of this size of joint is very extensive, so that it might work a hardship to change. The S. A. E. adopted in aircraft work, 28 threads per inch for the No. 12 size, and at the time of its adoption the criticism was that manufacturers could not buy from the tap makers No. 12 taps having 32 threads. It is apparent, however, from circularizing the manufacturers and users of ball-and-socket joints that the 32-pitch thread is satisfactory and that there apparently is no difficulty in obtaining No. 12-32 taps and dies.

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ALEX TAUB:—I would like to find out just where a ½-in. ball-and-socket joint could be used aside from drag-links. Why standardize it?

MR. EHRMAN:—The series was purposely extended to include the largest and smallest sizes proposed. It is difficult to determine the limits of the range of sizes, but to my personal knowledge the proposed largest and smallest sizes have been used; for what purposes, however, I do not know. Since there is a demand for them the Division believes a standard should be established as a guide.

CHAIRMAN B. B. BACHMAN:—I think that the answer to Mr. Taub's question is that the Society is dealing with not only passenger cars but trucks, tractors, marine apparatus, motorcycles, stationary internal-combustion engines and airplanes. This expands the field of our work to such an extent that the specifications of the Standards Committee to be complete must take into consideration requirements of all these different fields of automotive work. There are many of us who being interested in one particular line naturally may not see the reason for the extension of these standards outside of our own experience.

MR. TAUB:—Is it not a fact nevertheless that these larger sizes cannot be purchased from stock, but must be ordered specially?

MR. EHRMAN:—To illustrate the reason for the proposal, I will refer to the S. A. E. Standard screws. The sizes that are used most are carried in stock and the extreme lengths and the larger sizes have to be made to order. No one would be expected to carry 1½-in. S. A. E. screws in stock because there is so little call for them; still the standard covers this size.

F. C. GOLDSMITH:—The idea in this matter is to work out a suitable standard and have it adopted by the Society without waiting until individual practices become established.

Fuel Vacuum-Tank Mounting and Connections

This subject was proposed for standardization at the 1919 Summer Meeting of the Society. It was stated at that time that the vacuum method of regulating the flow of gasoline to the carbureter has been adopted for use on approximately 80 per cent of the different makes of automobiles, but that there was no standard practice for the

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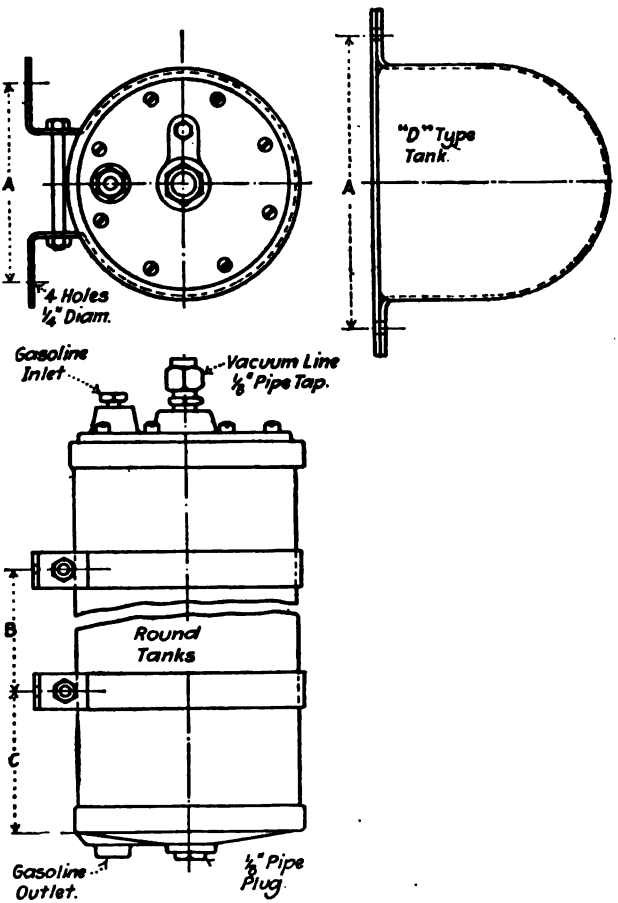

FUEL VACUUM-TANK MOUNTINGS

FUEL VACUUM-TANK MOUNTINGS AND CONNECTIONS

Tank Diameter, In.	[7]Gasoline Inlet	[7]Gasoline Outlet	A	B	C
3¾ and 4½	⅛	⅛	4	4	2½
6	⅛	¼	4	4	2½
"D" type	¼	¼	7¼	4	2½

All dimensions are in inches.
[7]Pipe-line connections and plugs are Briggs standard taper pipe threads.

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mounting dimensions or connections for the fuel and vacuum-pipe lines.

It will be noted that the pipe-line connections for the vacuum pipes and the gasoline inlets and outlets are specified as Briggs standard taper pipe threads and conform to S. A. E. Recommended Practice for carbureter fittings, pages 35a and 35b, S. A. E. Handbook, Vol. I.

The Miscellaneous Division has therefore recommended for adoption as S. A. E. Standard the fuel vacuum-tank mountings and pipe conections shown in the accompanying drawing and table.

Oilless Bushings

The Division has recommended for adoption as S. A. E. Recommended Practice the following sizes of oilless bushings. The subject was suggested as suitable for standardization by a manufacturer of bearings, as practically

DIMENSIONS FOR OILLESS BUSHINGS

Inside Diameter[4]	Length		Inside Diameter[4]	Length	
1/4	7/16	1/4	7/8	21/32	7/8
5/16	1/4	5/16	15/16	11/16	15/16
3/8	9/32	3/8	1	3/4	1
7/16	5/16	7/16	1 1/8	7/8	1 1/8
1/2	3/8	1/2	1 1/4	15/16	1 1/4
9/16	7/16	9/16	1 3/8	1	1 3/8
5/8	1 /32	5/8	1 1/2	1 1/8	1 1/2
11/16	1/2	11/16	1 5/8	1 1/4	1 5/8
3/4	9/16	3/4	1 3/4	1 5/16	1 3/4
13/16	5/8	13/16	2	1 1/2	2

Dimensions in inches.

Wall thickness: below 1¼ in. inside diameter, 1/32, 1/16, and ⅛ in.; above and including 1¼ in. inside diameter, 1/32, 1/16, ⅛ and 3/16 in.

[4]Inside diameter tolerances: below 1 in., + 0.001 or + 0.003 in.; above and including 1 in., + 0.001 or + 0.004 in.

every automobile builder specifies different size bushings, necessitating making these parts to order. Data were obtained from the industry showing sizes of bushings in use and the attendant recommendation represents a great reduction in the number of sizes.

Tank and Radiator Caps

The Division has recommended for adoption as S. A. E. Recommended Practice the following cap and plug types of tank and radiator caps. No thread tolerances were proposed by the Division, as it is desired to base them on

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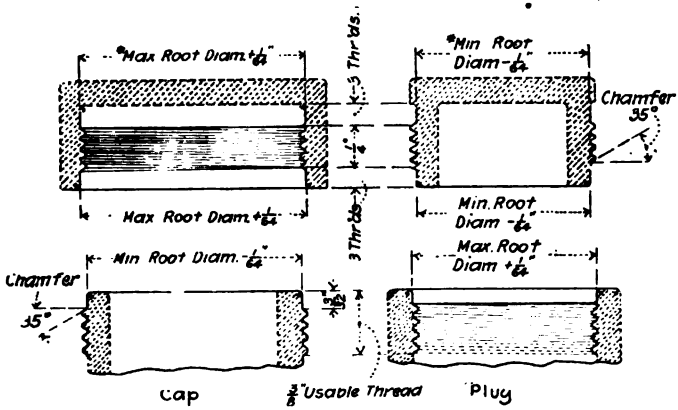

DIMENSIONS FOR RADIATOR AND FUEL TANK CAPS

Diameter	Pitch	Diameter	Pitch	Diameter	Pitch	Diameter	Pitch
1	20	1 1/2	18	2 1/4	16	3	16
1 1/8	18	1 3/4	16	2 1/2	16	3 1/2	16
1 1/4	18	2	16	2 3/4	16	4	16
1 3/8	18						

*Recess or neck is optional.
Corner radii are 1/32 in.
All threads are S. A. E. Fine.

the final report of the National Screw Thread Commission. A recess of three threads is specified for the cap in order to allow sufficient clearance for tapping.

This proposal is based on the recommendation made at the June, 1919, meeting of the Standards Committee, when it was referred back to the Division for further consideration. It was the consensus of opinion that the S. A. E. Standard fine threads should be specified rather than 16 U. S. Standard pitch for all sizes and that the 1/8-in. sizes should be eliminated. The original recommendation was based on data obtained from fifty-six companies representing both makers and users, and showed that there were in use by those companies sixty different types and sizes of fuel tank caps and fifty-eight different types and sizes of radiator caps.

The present recommendation is made after a careful review of automobile, tractor, aeronautic, marine, and stationary engine practice.

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Motorcycle Division

(Report as adopted by the Society)

Spark-Plug Shells

TAPPED HOLE DIMENSIONS

Diameter	Maximum		Minimum	
	Mm.	In.	Mm.	In.
Outside (full)	18.265	0.7191	18.115	0.7171
Pitch (effective)	17.127	0.6743	17.076	0.6723
Root (core)	16.152	0.6359	16.101	0.6339

SPARK-PLUG THREAD DIMENSIONS

Diameter	Maximum		Minimum	
	Mm.	In.	Mm.	In.
Outside (full)	18.001	0.7087	17.925	0.7057
Pitch (effective)	17.026	0.6703	16.949	0.6673
Root (core)	15.890	0.6256	15.839	0.6236

The Motorcycle Division has recommended that the thread limits for the present S. A. E. Recommended Practice for Spark-Plug Shells be extended to four decimal places and the millimeter equivalents included. The revision is proposed in order to provide a definite specification in accordance with good motorcycle engineering practice. This specification together with all other S. A. E. screw-thread standards will probably be more or less affected by the final report of the National Screw Thread Commission.

Non-Ferrous Metals Division

(Report as adopted by the Society)

There have been considerable advances in the art of manufacturing aluminum castings since the adoption of the present aluminum alloy standards in 1911, and the Non-Ferrous Metals Division has therefore undertaken to bring these standards into conformity with the best aluminum casting practice of today.

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Data have been obtained from manufacturers and users of non-ferrous metal alloys and considered by a Subdivision. The Division has recommended that the present S. A. E. Standard for Aluminum Alloys, page 13, S. A. E. Handbook, Vol. I, be revised to conform to the following proposal which is based on the subdivision report.

Aluminum Alloy—Specification No. 30

Aluminum, not less than, per cent	90.00
Copper, per cent	8.5 to 7.0

All other elements shall not exceed 1.7 per cent, of which not over 0.2 per cent shall be zinc. No other elements except silicon, iron, manganese and tin shall be allowed.

The tensile strength of test-specimens about ½ in. in diameter of this alloy cast in sand and tested without machining off the skin should be about 18,000 to 20,000 lb. per sq. in. and the elongation 1 to 2 per cent in 2 in.

This is a light alloy having a specific gravity of about 2.83 and is used more extensively in the automotive industry than all other light casting alloys combined. A shrinkage of 0.156 (5/32) in. per ft. should be allowed in pattern designs. This alloy is used for crankcases, oil-pans, steering-wheel spiders, differential carriers, transmission cases, camshaft housings, hub-caps and similar parts.

Aluminum Alloy—Specification No. 31

Aluminum, not less than, per cent	81.00
Copper, per cent	3.25 to 2.25
Zinc, per cent	14.5 to 12.5

All other elements shall not exceed 1.7 per cent. No other elements except silicon, iron, manganese and tin shall be allowed.

The tensile strength of test-specimens about ½ in. in diameter of this alloy cast in sand and tested without machining off the skin should be about 25,000 to 30,000 lb. per sq. in. with an elongation of more than 1 per cent in 2 in.

The specific gravity is about 3.0 and a shrinkage of 0.156 (5/32) in. per ft. should be allowed in pattern designs.

This alloy is used extensively in England for such

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parts as crankcases, oil-pans, steering-wheel spiders and transmission cases.

Aluminum Alloy—Specification No. 32

Aluminum, not less than, per cent	85.5
Copper, per cent	13.5 to 11.00

All other elements shall not exceed 1.7 per cent. The zinc shall not exceed 0.2 per cent. No other elements except silicon, iron, manganese and tin shall be allowed.

The tensile strength of test-specimens about ½ in. in diameter of this alloy cast in sand and tested without machining off the skin should be about 19,000 to 23,000 lb. per sq. in. and the elongation will be practically nothing.

The specific gravity of this alloy is about 2.95 and a shrinkage of 0.156 (5/32) in. per ft. should be allowed in pattern designs. This alloy is used for manifolds, pumps, carbureters, cylinders and other parts which should be free from leaks and where the brittleness of the alloy is not objectionable.

THE DISCUSSION

R. W. WOODWARD:—Specification No. 32 is changed entirely from an aluminum-zinc alloy to an aluminum-copper alloy and the properties of the new alloy are outlined.

A MEMBER:—With respect to the use of these alloys for pressure die castings, I do not believe any manufacturer would undertake a contract with any of these specifications. Every automobile on the market today has anywhere from ten to fifty die castings and the die-casting process must therefore be considered. Neither these chemical nor physical specifications can be applied to any die casting that is being produced today. One company at least produces about 2,000,000 lb. of aluminum die castings per month. While I admit that the specification from a purely theoretical standpoint may be all right, the practical application of the present-day methods has not been considered sufficiently and I think the reference to the use of the specifications for pressure die castings should be omitted.

F. W. ANDREW:—I believe that the statement that these formulas are not good for die castings is correct and that they should not be passed for that purpose.

CHAIRMAN B. B. BACHMAN:—Is it to be understood,

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therefore, that these compositions are suitable for sand castings?

MR. WOODWARD:—I think these specifications were drawn up principally for use in making sand castings. The preparation of formulas for die-casting alloys will be taken up separately by the Division.

MARINE DIVISION

(Report as adopted by the Society)

Water-Pipe Flanges

Present marine practice is to use S. A. E. Standard carbureter flanges for water-pipe flanges. The Division has therefore recommended the following proposal for adoption as S. A. E. Recommended Practice:

> The present S. A. E. Standard for two and four-bolt type carbureter flanges given on data sheets 35 and 35xa, S. A. E. Handbook, Vol. I, is S. A. E. Recommended Practice for Water-Pipe Flanges.

Motorboat Control Levers

The Marine Division feels that standardization of the direction of the movement of motorboat control levers will simplify the handling of motorboats and decrease the number of accidents caused by unfamiliarity with controls and has therefore proposed the following recommendaton for adoption as S.A.E. Standard:

> For spark and throttle control levers for motorboats intended for one-man control, the spark lever should be shorter than the throttle lever and both should be mounted on stationary sectors. The sectors should be placed so that the levers are moved forward or upward to advance the spark or to open the throttle.
>
> The gearshift lever should be placed so that it is moved forward to pass from neutral to ahead and backward to pass from neutral to reverse.

Reverse Couplings—Steel

The present S. A. E. Standard for Steel Reverse Couplings has been criticised because the nuts specified do not conform to the S. A. E. Standard, causing unnecessary expense and trouble in obtaining special nuts for use in standard couplings. The Division has, therefore, proposed that the present standard be revised so as to allow the use of S. A. E. Standard nuts. The proposed nut

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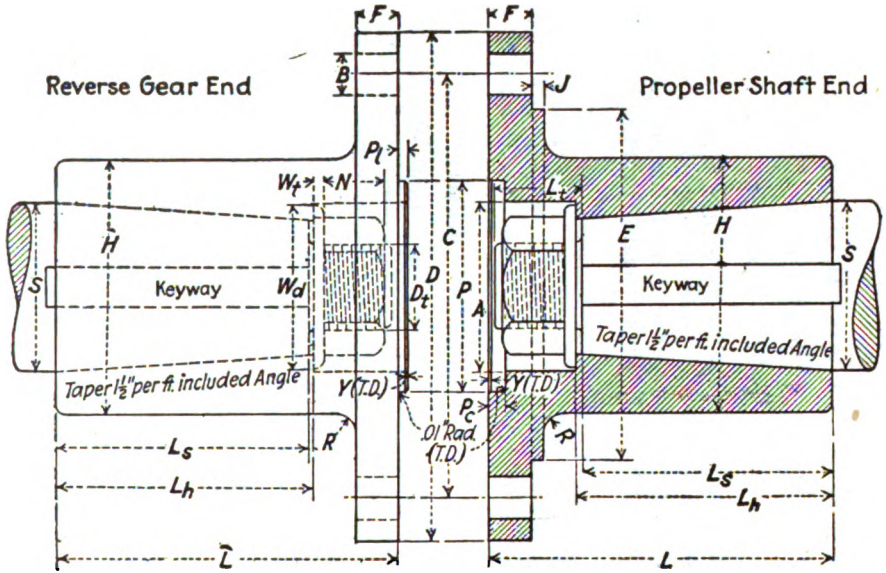

MOTORBOAT STEEL REVERSE COUPLINGS.

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DIMENSIONS FOR MOTORBOAT STEEL REVERSE COUPLINGS

Size No. (See Note)	Shaft and Nut[8]						Key-way		Wash-er		Flange					Pilot				Hub				Bolts, S. A. E.		
	S	Le	Dt	N	[9]Thds. S.A.E.	Lt	Width	Height	Wd	Wt	D	E	F	J	A	[10]P	P1	Pe	Y	H	L	Lh	R	No.	[11]B	C
RPS- 8	1	1 13/16	9/16	21/64	18	11/16	1/4	1/8	1 9/16	1/8	4	2 13/32	3/8	1/16	1 3/8	1 5/8	1/16	1/8	1/64	1 7/8	2 9/16	1 7/8	3/16	4	3/8	3
RPS- 9	1 1/8	1 13/16	9/16	21/64	18	11/16	1/4	1/8	1 9/16	1/8	4	2 13/32	3/8	1/16	1 3/8	1 5/8	1/16	1/8	1/64	1 7/8	2 9/16	1 7/8	3/16	4	3/8	3
RPS-10	1 1/4	2 3/16	3/4	21/32	16	7/8	5/16	5/32	1 7/16	1/8	5	3 11/32	7/16	3/32	1 3/4	2	1/8	3/16	1/32	2 3/8	3 1/8	2 1/4	7/32	6	7/16	4
RPS-11	1 3/8	2 3/16	3/4	21/32	16	7/8	3/8	3/16	1 7/16	1/8	5	3 11/32	7/16	3/32	1 3/4	2	1/8	3/16	1/32	2 3/8	3 1/8	2 1/4	7/32	6	7/16	4
RPS-12	1 1/2	2 3/16	3/4	21/32	16	7/8	3/8	3/16	1 7/16	1/8	5	3 11/32	7/16	3/32	1 3/4	2	1/8	3/16	1/32	2 3/8	3 1/8	2 1/4	7/32	6	7/16	4
RPS-13	1 5/8	2 3/16	3/4	21/32	16	7/8	3/8	3/16	1 7/16	1/8	5	3 11/32	7/16	3/32	1 3/4	2	1/8	3/16	1/32	2 3/8	3 1/8	2 1/4	7/32	6	7/16	4
RPS-14	1 3/4	2 1/16	1	7/8	14	1 1/8	7/16	7/32	1 13/16	1/8	6	4 1/16	1/2	1/8	2 3/16	2 1/2	1/8	3/16	1/32	3	4 1/8	3	1/4	6	9/16	5
RPS-15	1 7/8	2 1/16	1	7/8	14	1 1/8	1/2	1/4	1 13/16	1/8	6	4 1/16	1/2	1/8	2 3/16	2 1/2	1/8	3/16	1/32	3	4 1/8	3	1/4	6	9/16	5
RPS-16	2	2 1/16	1	7/8	14	1 1/8	1/2	1/4	1 13/16	3/16	6	4 1/16	1/2	1/8	2 3/16	2 1/2	1/8	3/16	1/32	3	4 1/8	3	1/4	6	9/16	5
RPS-18	2 1/4	3 1/2 16	1 1/8	63/64	12	1 5/16	5/8	5/16	2 7/16	3/16	7	4 1/2	5/8	1/8	2 1/2	3	3/16	1/4	1/32	3 1/4	5 3/4	3 7/8	5/16	6	5/8	5 1/2
RPS-20	2 1/2	3 1/2 16	1 1/8	63/64	12	1 5/16	5/8	5/16	2 7/16	3/16	7	4 1/2	5/8	1/8	2 1/2	3	3/16	1/4	1/32	3 1/4	5 3/4	3 7/8	5/16	6	5/8	5 1/2
RPS-22	2 3/4	4 1/8	1 3/8	1 13/64	12	1 5/8	3/4	3/8	2 15/16	1/4	8	5 3/8	3/4	1/8	3	3 3/4	1/4	5/16	3/64	4 3/8	5 7/8	4 1/4	3/8	6	3/4	6 1/2
RPS-24	3	4 3/8	1 3/8	1 13/64	12	1 5/8	3/4	3/8	2 15/16	1/4	8	5 3/8	3/4	1/8	3	3 3/4	1/4	5/16	3/64	4 3/8	6 3/8	4 3/4	3/8	6	3/4	6 1/2
RPS-26	3 1/4	5 7/16	1 1/2	1 5/16	12	1 13/16	7/8	7/16	3 7/16	1/4	9	6 1/16	7/8	3/16	3 3/4	4 3/8	1/4	5/16	3/64	5	7 3/8	5 5/8	7/16	6	7/8	7 3/8
RPS-28	3 1/2	5 7/16	1 3/4	1 17/32	12	2 1/16	7/8	7/16	3 7/16	1/4	9	6 1/16	7/8	3/16	3 3/4	4 3/8	1/4	5/16	3/64	5	7 3/8	5 5/8	7/16	6	7/8	7 3/8
RPS-32	4	6 1/4	2	1 3/4	12	2 7/16	1	1/2	3 15/16	5/16	10	6 1/2	1	3/16	4 1/4	5	5/16	3/8	3/64	6	8 13/16	6 1/2	1/2	6	1	8

T. D. indicates tooling dimension. Dimensions in inches.

NOTE.—In column "Size No." R indicates Reverse Gear: P, Propeller Shaft: S, Steel, and the figures the number of eighths of an inch in shaft diameters.

[8]Nuts for Size No. RPS-26 and RPS-28 use 2 3/4-in. hexagon stock. Nuts for Size No. RPS-32 use 3-in. hexagon stock.

[9]All threads to be S. A. E. pitch, U. S. Form. See pages 4 and 4c, S. A. E. Handbook, Vol. I.

[10]Pilot tolerance, +0.000,—0.001 in. per in. of diameter. Pilot recess tolerance, +0.001,—0.000 in. per in. of diameter.

[11]Figures in column indicate bolt diameters. Use clearance drill of same nominal size for holes B in flange.

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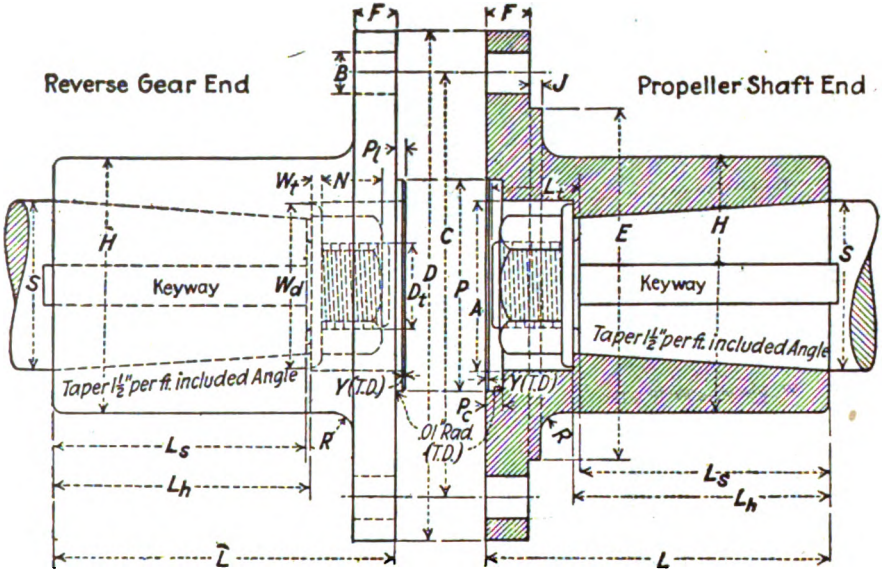

MOTORBOAT STEEL REVERSE COUPLINGS.

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DIMENSIONS FOR MOTORBOAT STEEL REVERSE COUPLINGS

Size No. (See Note)	Shaft and Nuts						Key-way		Wash-er		Flange					Pilot				Hub				Bolts, S. A. E.		
	S	Ls	Dt	N	[9]Thds. S.A.E.	Lt	Width	Height	Wd	Wt	D	E	F	J	A	[10]P	P1	Pe	Y	H	L	Lh	R	No.	[11]B	C
RPS- 8	1	1 13/16	9/16	31/64	18	11/16	1/4	1/8	1 3/16	1/8	4	2 13/32	3/8	1/16	1 3/8	1 5/8	1/16	1/8	1/64	1 7/8	2 9/16	1 7/8	3/16	4	3/8	3
RPS- 9	1 1/8	1 13/16	9/16	31/64	18	11/16	1/4	1/8	1 3/16	1/8	4	2 13/32	3/8	1/16	1 3/8	1 5/8	1/16	1/8	1/64	1 7/8	2 9/16	1 7/8	3/16	4	3/8	3
RPS-10	1 1/4	2 3/16	3/4	21/32	16	7/8	5/16	5/32	1 7/16	1/8	5	3 11/32	7/16	3/32	1 3/4	2	1/8	3/16	1/32	2 3/8	3 1/8	2 1/4	7/32	6	7/16	4
RPS-11	1 3/8	2 3/16	3/4	21/32	16	7/8	3/8	3/16	1 7/16	1/8	5	3 11/32	7/16	3/32	1 3/4	2	1/8	3/16	1/32	2 3/8	3 1/8	2 1/4	7/32	6	7/16	4
RPS-12	1 1/2	2 3/16	3/4	21/32	16	7/8	3/8	3/16	1 7/16	1/8	5	3 11/32	7/16	3/32	1 3/4	2	1/8	3/16	1/32	2 3/8	3 1/8	2 1/4	7/32	6	7/16	4
RPS-13	1 5/8	2 3/16	3/4	21/32	16	7/8	3/8	3/16	1 7/16	1/8	5	3 11/32	7/16	3/32	1 3/4	2	1/8	3/16	1/32	2 3/8	3 1/8	2 1/4	7/32	6	7/16	4
RPS-14	1 3/4	2 15/16	1	7/8	14	1 1/8	7/16	7/32	1 15/16	1/8	6	4 1/16	1/2	1/8	2 3/16	2 1/2	1/8	3/16	1/32	3	4 1/8	3	1/4	6	9/16	5
RPS-15	1 7/8	2 15/16	1	7/8	14	1 1/8	1/2	1/4	1 15/16	1/8	6	4 1/16	1/2	1/8	2 3/16	2 1/2	1/8	3/16	1/32	3	4 1/8	3	1/4	6	9/16	5
RPS-16	2	2 15/16	1	7/8	14	1 1/8	1/2	1/4	1 15/16	3/16	6	4 1/16	1/2	1/8	2 3/16	2 1/2	1/8	3/16	1/32	3	4 1/8	3	1/4	6	9/16	5
RPS-18	2 1/4	3 13/16	1 1/8	63/64	12	1 5/16	5/8	5/16	2 7/16	3/16	7	4 1/2	5/8	1/8	2 1/2	3	3/16	1/4	1/32	3 3/4	5 3/16	3 7/8	5/16	6	5/8	5 1/2
RPS-20	2 1/2	3 13/16	1 1/8	63/64	12	1 5/16	5/8	5/16	2 7/16	3/16	7	4 1/2	5/8	1/8	2 1/2	3	3/16	1/4	1/32	3 3/4	5 3/16	3 7/8	5/16	6	5/8	5 1/2
RPS-22	2 3/4	4 1/8	1 3/8	1 13/64	12	1 5/8	3/4	3/8	2 15/16	1/4	8	5 3/8	3/4	1/8	3	3 3/4	1/4	5/16	3/64	4 3/8	5 7/8	4 1/4	3/8	6	3/4	6 1/2
RPS-24	3	4 5/8	1 3/8	1 13/64	12	1 5/8	3/4	3/8	2 15/16	1/4	8	5 3/8	3/4	1/8	3	3 3/4	1/4	5/16	3/64	4 3/8	6 3/8	4 3/4	3/8	6	3/4	6 1/2
RPS-26	3 1/4	5 7/16	1 1/2	1 5/16	12	1 13/16	7/8	7/16	3 7/16	1/4	9	6 1/16	7/8	3/16	3 3/4	4 3/8	1/4	5/16	3/64	5	7 3/8	5 5/8	7/16	6	7/8	7 3/8
RPS-28	3 1/2	5 7/16	1 3/4	1 17/32	12	2 1/16	7/8	7/16	3 7/16	1/4	9	6 1/16	7/8	3/16	3 3/4	4 3/8	1/4	5/16	3/64	5	7 5/8	5 5/8	7/16	6	7/8	7 3/8
RPS-32	4	6 1/4	2	1 3/4	12	2 7/16	1	1/2	3 15/16	5/16	10	6 1/2	1	9/16	4 1/4	5	5/16	3/8	3/64	6	8 13/16	6 1/2	1/2	6	1	8

T. D. indicates tooling dimension. Dimensions in inches.

NOTE.—In column "Size No." R indicates Reverse Gear: P, Propeller Shaft: S, Steel, and the figures the number of eighths of an inch in shaft diameters.

[8]Nuts for Size No. RPS-26 and RPS-28 use 2 9/4-in. hexagon stock. Nuts for Size No. RPS-32 use 3-in. hexagon stock.

[9]All threads to be S. A. E. pitch, U. S. Form. See pages 4 and 4c, S. A. E. Handbook, Vol. I.

[10]Pilot tolerance, +0.000,—0.001 in. per in. of diameter. Pilot recess tolerance, +0.001,—0.000 in. per in. of diameter.

[11]Figures in column indicate bolt diameters. Use clearance drill of same nominal size for holes B in flange.

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thicknesses for thread diameters of over 1½-in. were determined according to the empirical formula for the smaller standard sizes: thickness = ⅞ of bolt diameter.

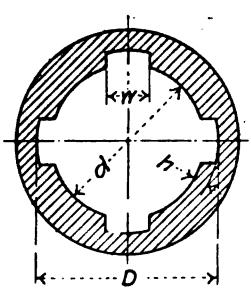
Shaft Fittings Division

(Report as adopted by the Society)

The Shaft Fittings Division has obtained the consensus of opinion of the industry in reference to the present spline fitting standards upon which the following revisions and extensions presented for adoption are based. The revised tolerances and proposed corner radii are recommended as being in accordance with the best engineering practice.

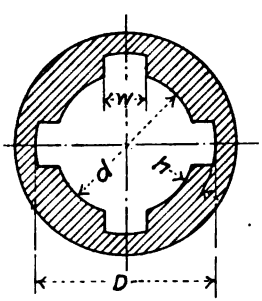
Four-Spline Fittings

The Division has recommended that the tolerance for width W of the present S.A.E. Standard for Four-Spline Fittings be increased by 0.001 in., making the total tolerance 0.002 in. for nominal diameter from ¾ to 1¾ in. inclusive and 0.003 in. from 2 to 3 in. inclusive; and that a maximum radius of 0.015 in. be specified for the corners of the splines.



4A

W = 0.241D
h = 0.075D
d = 0.850D



4B

W = 0.241D
h = 0.125D
d = 0.750D

Four-Spline Shaft Fittings

THE DISCUSSION

C. W. Spicer:—The increasing use of spline fittings in tractor work as well as some large-size shafts required in war work has made it exceedingly desirable to extend the present standards. It will be recalled that several years ago there was a question whether there should be a speci-

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DIMENSIONS FOR FOUR-SPLINE SHAFT FITTINGS

4A—PERMANENT FIT

Nom Diam	D		d		W		h		[12]T
	max	min	max	min	max	min	max	min	
3/4	0.750	0.749	0.637	0.636	0.181	0.179	0.056	0.055	78
7/8	0.875	0.874	0.744	0.743	0.211	0.209	0.066	0.065	107
1	1.000	0.999	0.850	0.849	0.241	0.239	0.075	0.074	139
1 1/8	1.125	1.124	0.956	0.955	0.271	0.269	0.084	0.083	175
1 1/4	1.250	1.249	1.062	1.061	0.301	0.299	0.094	0.093	217
1 3/8	1.375	1.374	1.169	1.168	0.331	0.329	0.103	0.102	262
1 1/2	1.500	1.499	1.275	1.274	0.361	0.359	0.112	0.111	311
1 5/8	1.625	1.624	1.381	1.380	0.391	0.389	0.122	0.121	367
1 3/4	1.750	1.749	1.487	1.486	0.422	0.420	0.131	0.130	424
2	2.000	1.998	1.700	1.698	0.482	0.479	0.150	0.148	555
2 1/4	2.250	2.248	1.912	1.910	0.542	0.539	0.169	0.167	703
2 1/2	2.500	2.498	2.125	2.123	0.602	0.599	0.187	0.185	865
3	3.000	2.998	2.550	2.548	0.723	0.720	0.225	0.223	1,249

4B—TO SLIDE WHEN NOT UNDER LOAD

Nom Diam	D		d		W		h		[12]T
	max	min	max	min	max	min	max	min	
3/4	0.750	0.749	0.562	0.561	0.181	0.179	0.094	0.093	123
7/8	0.875	0.874	0.656	0.655	0.211	0.209	0.109	0.108	167
1	1.000	0.999	0.750	0.749	0.241	0.239	0.125	0.124	219
1 1/8	1.125	1.124	0.844	0.843	0.271	0.269	0.141	0.140	277
1 1/4	1.250	1.249	0.937	0.936	0.301	0.299	0.156	0.155	341
1 3/8	1.375	1.374	1.031	1.030	0.331	0.329	0.172	0.171	414
1 1/2	1.500	1.499	1.125	1.124	0.361	0.359	0.187	0.186	491
1 5/8	1.625	1.624	1.219	1.218	0.391	0.389	0.203	0.202	577
1 3/4	1.750	1.749	1.312	1.311	0.422	0.420	0.219	0.218	670
2	2.000	1.998	1.500	1.498	0.482	0.479	0.250	0.248	875
2 1/4	2.250	2.248	1.687	1.685	0.542	0.539	0.281	0.279	1,106
2 1/2	2.500	2.498	1.875	1.873	0.602	0.599	0.312	0.310	1,365
3	3.000	2.998	2.250	2.248	0.723	0.720	0.375	0.373	1,969

Dimensions in inches.
Radii on corners of splines not to exceed 0.015 in.
Splines shall not be more than 0.006 in. per ft. out of parallel with respect to the axis of the shaft.
[12]Torque = 1000x4x mean Rxhx1 = pound-inches torque capacity per inch of bearing length at 1000 lb. per sq. in. pressure on sides of splines.
No allowance is made for radii on corners nor for clearances.

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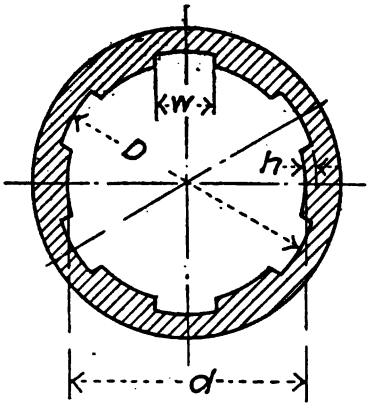
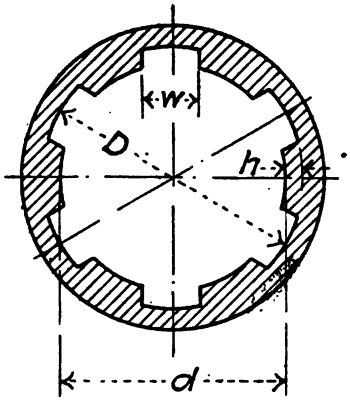


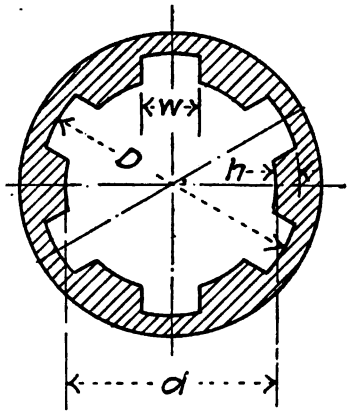
6A

W = 0.250D
h = 0.050D
d = 0.900D



6B

W = 0.250D
h = 0.075D
d = 0.850D



6C

W = 0.250D
h = 0.100D
d = 0.800D

JIX-SPLINE SHAFT FITTINGS

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DIMENSIONS FOR SIX-SPLINE SHAFT FITTINGS

6A—PERMANENT FIT

Nom Diam	D		d		W		[12]T
	max	min	max	min	max	min	
¾	0.750	0.749	0.675	0.674	0.188	0.186	80
⅞	0.875	0.874	0.788	0.787	0.219	0.217	109
1	1.000	0.999	0.900	0.899	0.250	0.248	143
1⅛	1.125	1.124	1.013	1.012	0.281	0.279	180
1¼	1.250	1.249	1.125	1.124	0.313	0.311	223
1⅜	1.375	1.374	1.238	1.237	0.344	0.342	269
1½	1.500	1.499	1.350	1.349	0.375	0.373	321
1⅝	1.625	1.624	1.463	1.462	0.406	0.404	376
1¾	1.750	1.749	1.575	1.574	0.438	0.436	436
2	2.000	1.998	1.800	1.798	0.500	0.497	570
2¼	2.250	2.248	2.025	2.023	0.563	0.560	721
2½	2.500	2.498	2.250	2.248	0.625	0.622	891
3	3.000	2.998	2.700	2.698	0.750	0.747	1,283

6B—TO SLIDE WHEN NOT UNDER LOAD

Nom Diam	D		d		W		[12]T
	max	min	max	min	max	min	
¾	0.750	0.749	0.638	0.637	0.188	0.186	117
⅞	0.875	0.874	0.744	0.743	0.219	0.217	159
1	1.000	0.999	0.850	0.849	0.250	0.248	208
1⅛	1.125	1.124	0.956	0.955	0.281	0.279	263
1¼	1.250	1.249	1.063	1.062	0.313	0.311	325
1⅜	1.375	1.374	1.169	1.168	0.344	0.342	393
1½	1.500	1.499	1.275	1.274	0.375	0.373	468
1⅝	1.625	1.624	1.381	1.380	0.406	0.404	550
1¾	1.750	1.749	1.488	1.487	0.438	0.436	637
2	2.000	1.998	1.700	1.698	0.500	0.497	833
2¼	2.250	2.248	1.913	1.912	0.563	0.560	1,052
2½	2.500	2.498	2.125	2.123	0.625	0.622	1,300
3	3.000	2.998	2.550	2.548	0.750	0.747	1,873

6C—TO SLIDE WHEN UNDER LOAD

Nom Diam	D		d		W		[12]T
	max	min	max	min	max	min	
¾	0.750	0.749	0.600	0.599	0.188	0.186	152
⅞	0.875	0.874	0.700	0.699	0.219	0.217	207
1	1.000	0.999	0.800	0.799	0.250	0.248	270
1⅛	1.125	1.124	0.900	0.899	0.281	0.279	342
1¼	1.250	1.249	1.000	0.999	0.313	0.311	421
1⅜	1.375	1.374	1.100	1.099	0.344	0.342	510
1½	1.500	1.499	1.200	1.199	0.375	0.373	608
1⅝	1.625	1.624	1.300	1.299	0.406	0.404	713
1¾	1.750	1.749	1.400	1.399	0.438	0.436	827
2	2.000	1.998	1.600	1.598	0.500	0.497	1,080
2¼	2.250	2.248	1.800	1.798	0.563	0.560	1,367
2½	2.500	2.498	2.000	1.998	0.625	0.622	1,688
3	3.000	2.998	2.400	2.398	0.750	0.747	2,430

Dimensions in inches
Radii on corners of splines not to exceed 0.015 in.
Splines shall not be more than 0.006 in. per ft. out of parallel with respect to the axis of the shaft.
[12]Torque = 1000x6x mean Rxhx1 = pound-inches torque capacity per inch of bearing length at 1000 lb. per sq. in. pressure on side of splines.
No allowance is made for radii on corners nor for clearances.

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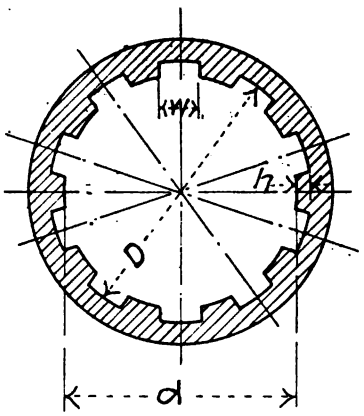
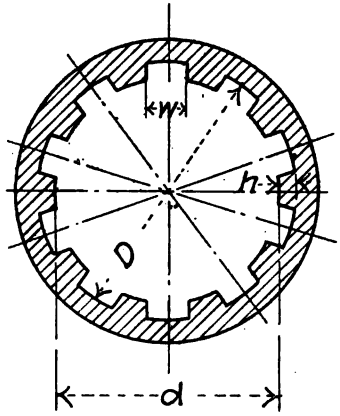


10A
W = 0.156D
h = 0.045D
d = 0 910D



10B
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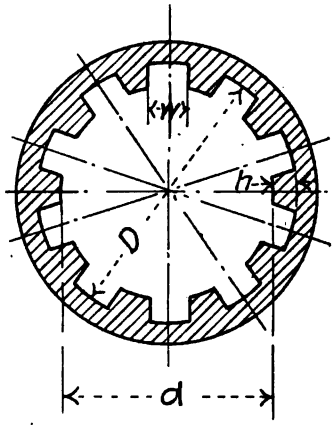
d = 0 860D



10C
W = 0.156D
h = 0 095D
d = 0 810D

TEN-SPLINE SHAFT FITTINGS

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DIMENSIONS FOR TEN-SPLINE SHAFT FITTINGS

10A—PERMANENT FIT								10B—TO SLIDE WHEN NOT UNDER LOAD								10C—TO SLIDE WHEN UNDER LOAD							
Nom Diam	D		d		W		[14]T	Nom Diam	D		d		W		[14]T	Nom Diam	D		d		W		[14]T
	max	min	max	min	max	min			max	min	max	min	max	min			max	min	max	min	max	min	
¾	0.750	0.749	0.693	0.692	0.117	0.115	120	¾	0.750	0.749	0.645	0.644	0.117	0.115	1833	¾	0.750	0.749	0.608	0.607	0.117	0.115	241
⅞	0.875	0.874	0.796	0.795	0.137	0.135	165	⅞	0.875	0.874	0.753	0.752	0.137	0.135	248	⅞	0.875	0.874	0.709	0.708	0.137	0.135	329
1	1.000	0.999	0.910	0.909	0.156	0.154	215	1	1.000	0.999	0.860	0.859	0.156	0.154	326	1	1.000	0.999	0.810	0.809	0.156	0.154	430
1⅛	1.125	1.124	1.024	1.023	0.176	0.174	271	1⅛	1.125	1.124	0.963	0.957	0.176	0.174	412	1⅛	1.125	1.124	0.911	0.910	0.176	0.174	545
1¼	1.250	1.249	1.138	1.137	0.195	0.193	336	1¼	1.250	1.249	1.075	1.074	0.195	0.193	508	1¼	1.250	1.249	1.013	1.012	0.195	0.193	672
1⅜	1.375	1.374	1.251	1.250	0.215	0.213	406	1⅜	1.375	1.374	1.183	1.182	0.215	0.213	614	1⅜	1.375	1.374	1.114	1.113	0.215	0.213	813
1½	1.500	1.499	1.365	1.364	0.234	0.232	483	1½	1.500	1.499	1.290	1.289	0.234	0.232	732	1½	1.500	1.499	1.215	1.214	0.234	0.232	967
1⅝	1.625	1.624	1.479	1.478	0.254	0.252	566	1⅝	1.625	1.624	1.398	1.397	0.254	0.252	860	1⅝	1.625	1.624	1.316	1.315	0.254	0.252	1,135
1¾	1.750	1.749	1.593	1.592	0.273	0.271	658	1¾	1.750	1.749	1.505	1.504	0.273	0.271	997	1¾	1.750	1.749	1.418	1.417	0.273	0.271	1,316
2	2.000	1.998	1.820	1.818	0.312	0.309	860	2	2.000	1.998	1.720	1.718	0.312	0.309	1,302	2	2.000	1.998	1.620	1.618	0.312	0.309	1,720
2¼	2.250	2.248	2.048	2.046	0.351	0.348	1,088	2¼	2.250	2.248	1.935	1.933	0.351	0.348	1,647	2¼	2.250	2.248	1.823	1.821	0.351	0.348	2,176
2½	2.500	2.498	2.275	2.273	0.390	0.387	1,343	2½	2.500	2.498	2.150	2.148	0.390	0.387	2,034	2½	2.500	2.498	2.025	2.023	0.390	0.387	2,688
3	3.000	2.998	2.730	2.728	0.468	0.465	1,934	3	3.000	2.998	2.580	2.578	0.468	0.465	2,929	3	3.000	2.998	2.430	2.428	0.468	0.465	3,869
3½	3.500	3.497	3.185	3.182	0.546	0.543	2,632	3½	3.500	3.497	3.010	3.007	0.546	0.543	3,987	3½	3.500	3.497	2.835	2.832	0.546	0.543	5,266
4	4.000	3.997	3.640	3.637	0.624	0.621	3,438	4	4.000	3.997	3.440	3.437	0.624	0.621	5,208	4	4.000	3.997	3.240	3.237	0.624	0.621	6,878
4½	4.500	4.497	4.095	4.092	0.702	0.699	4,351	4½	4.500	4.497	3.870	3.867	0.702	0.699	6,591	4½	4.500	4.497	3.645	3.642	0.702	0.699	8,705
5	5.000	4.997	4.550	4.547	0.780	0.777	5,371	5	5.000	4.997	4.300	4.297	0.780	0.777	8,137	5	5.000	4.997	4.050	4.047	0.780	0.777	10,746
5½	5.500	5.497	5.005	5.002	0.858	0.855	6,500	5½	5.500	5.497	4.730	4.727	0.858	0.855	9,846	5½	5.500	5.497	4.455	4.452	0.858	0.855	13,003
6	6.000	5.997	5.460	5.457	0.936	0.933	7,735	6	6.000	5.997	5.160	5.157	0.936	0.933	11,718	6	6.000	5.997	4.860	4.857	0.936	0.933	15,475

Dimensions in inches.
Radii on corner of splines not to exceed 0.015 in.
Splines shall not be more than 0.006 in. per ft. out of parallel with respect to the axis of the shaft.
[14]Torque = 1000x10x mean Rxhx1 = pound-inches torque capacity per inch of bearing length at 1000 lb. per sq. in. pressure on sides of splines.
No allowance is made for radii on corners nor for clearances.

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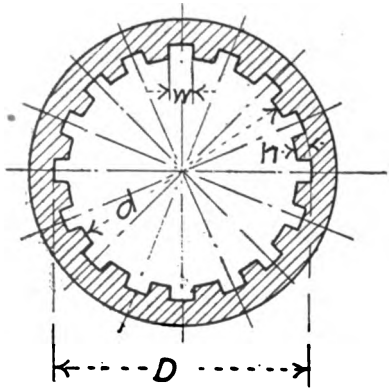
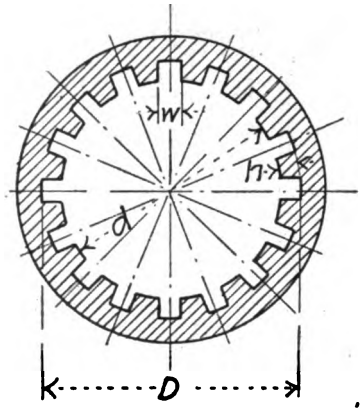
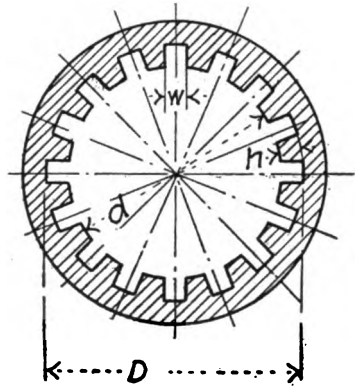


16A
W = 0.098D
h = 0.045D
d = 0.910D



16B
W = 0.098D
h = 0.070D
d = 0.860D



16C
W = 0.098D
h = 0 0`5D
d = 0.810D

SIXTEEN-SPLINE SHAFT FITTINGS

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DIMENSIONS FOR SIXTEEN-SPLINE SHAFT FITTINGS

16A—PERMANENT FIT

Nom Diam	D		d		W		[15]T
	max	min	max	min	max	min	
2	2.000	1.997	1.820	1.817	0.196	0.193	1,375
2½	2.500	2.497	2.275	2.273	0.245	0.242	2,149
3	3.000	2.997	2.730	2.727	0.294	0.291	3,094
3½	3.500	3.497	3.185	3.182	0.343	0.340	4,212
4	4.000	3.997	3.640	3.637	0.392	0.389	5,501
4½	4.500	4.497	4.095	4.092	0.441	0.438	6,962
5	5.000	4.997	4.550	4.547	0.490	0.487	8,595
5½	5.500	5.497	5.005	5.002	0.539	0.536	10,395
6	6.000	5.997	5.460	5.457	0.588	0.585	12,377

16B—TO SLIDE WHEN NOT UNDER LOAD

Nom Diam	D		d		W		[15]T
	max	min	max	min	max	min	
2	2.000	1.997	1.720	1.717	0.196	0.193	2,083
2½	2.500	2.497	2.150	2.147	0.245	0.242	3,255
3	3.000	2.997	2.580	2.577	0.294	0.291	4,687
3½	3.500	3.497	3.010	3.007	0.343	0.340	6,378
4	4.000	3.997	3.440	3.437	0.392	0.389	8,333
4½	4.500	4.497	3.870	3.867	0.441	0.438	10,546
5	5.000	4.997	4.300	4.297	0.490	0.487	13,020
5½	5.500	5.497	4.730	4.727	0.539	0.536	15,754
6	6.000	5.997	5.160	5.157	0.588	0.585	18,749

16C—TO SLIDE WHEN UNDER LOAD

Nom Diam	D		d		W		[15]T
	max	min	max	min	max	min	
2	2.000	1.997	1.620	1.617	0.196	0.193	2,751
2½	2.500	2.497	2.025	2.022	0.245	0.242	4,299
3	3.000	2.997	2.430	2.427	0.294	0.291	6,190
3½	3.500	3.497	2.835	2.832	0.343	0.340	8,426
4	4.000	3.997	3.240	3.237	0.392	0.389	11,005
4½	4.500	4.497	3.645	3.642	0.441	0.438	13,928
5	5.000	4.997	4.050	4.047	0.490	0.487	17,195
5½	5.500	5.497	4.455	4.452	0.539	0.536	20,806
6	6.000	5.997	4.860	4.857	0.588	0.585	24,760

Dimensions in inches.
Radii on corner of splines not to exceed 0.015 in.
Splines shall not be more than 0.006 in. per ft. out of parallel with respect to the axis of the shaft.
[15]Torque = 1000x16x mean Rxhx1 = pound-inches torque capacity per inch of bearing length at 1000 lb. per sq. in. pressure on sides of splines.
No allowance is made for radii on corners nor for clearances.

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fied radius at the corners of the spline. At that time it was considered theoretically desirable but not practically possible. It will be exceedingly difficult and expensive to adopt any given radius, but if the splines are made with square corners these cannot be maintained for any length of time as the corners in the tools and pieces will gradually wear down. It is therefore considered advisable to specify the maximum radius for the corners of the spline. This applies also to the six and ten-Spline Fittings.

Six-Spline Fittings

The Division has recommended that the tolerance for width W of the present S.A.E. Standard for Six-Spline Fittings be increased by 0.001 in., making the total tolerance 0.002 in. for nominal diameters from ¾ to 1¾ in. inclusive and 0.003 in. from 2 to 3 in. inclusive; and that a maximum radius of 0.015 in. be specified for the corners of the splines.

Ten-Spline Fittings

The Division has recommended that the tolerance for width W of the present S.A.E. Standard for Ten-Spline Fittings be increased by 0.001 in., making the total tolerance 0.002 in. for nominal diameters from ¾ to 1¾ in. inclusive and 0.003 in. from 2 to 3 in. inclusive; that a maximum radius of 0.015 in. be specified for the corners of the splines; and that the standard be extended to include 6-in. and intermediate nominal diameters.

Sixteen-Spline Fittings

Twelve-spline fittings in diameters up to and including 5 in. have been used to a limited extent in the automotive industry. The Shaft Fittings Division does not wish to encourage the use of a fitting with the number of splines only slightly more than those of the ten-spline fitting, and has therefore proposed for adoption the following sixteen-spline fitting, which is considered preferable to a twelve-spline fitting. The sixteen-spline fitting will permit greater shaft strength, owing to the smaller height of the splines, than either a ten- or twelve-spline fitting.

THE DISCUSSION

C. W. SPICER:—Requirements in war work made it necessary in some cases to use spline fittings as large as 5 in. in diameter. These larger diameters naturally require more than ten splines, and in practice eighteen or twenty splines were used. Twelve splines are also in

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use but this fitting is so close to the ten-spline that it does not seem desirable to have such a new standard. The sixteen-spline fitting has therefore been developed somewhat as a compromise due to the existing conditions.

Stationary Engine and Lighting Plant Division

(Report as adopted by the Society)

Approval of Existing S. A. E. Standards

The Division has approved the following S. A. E. Standards and Recommended Practices as satisfactory for stationary engine practice:

	Data Sheet
Adjustable Yoke Rod-Ends	1
Plan Yoke Rod-Ends	1a
Eye Rod-Ends	2
Rod-End Pins	2a
Cotter-Pins	2b
Spark-Plug Shells	3
Nuts for Machine Screws	3c
Screws and Bolts	4, 4a
Screw Threads	4c
Lock Washers	5
Taper Fittings with Castle Nuts	7e
Steel Specifications	9, 9a, 9b, 9c, 9d
Valve Metals	10
Babbitt Metal	11
Bearing Metals	11
Brass Casting Metals	12
Cast Manganese Bronze	12a
Manganese Bronze Sheets and Rods	12b, 12c
Hard Cast Bronze	12d
Gear Bronze	12d
Aluminum Alloys	13
Brass Sheets and Strips	13a
Brass Rods	13b
Tobin Bronze Rods	13b
Non-Ferrous Metal Tubing	13c
Pitch of Silent Chains	14b
Widths of Silent Chains	14b
Roller-Chain Dimensions	14c
Round Tension Test-Specimen	15
Flat Tension Test-Specimen	15xa
Flat Tension Test-Specimen	15a
Shock Test-Specimen	15xb
Gray-Iron Test-Specimen	15b, 15c
Brinell Hardness Test	15xd

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	Data Sheet
Cold-Drawn Seamless Steel Tubes	16
Steel Bands and Strips	17
Annular Ball Bearings	29, 29a, 29b, 29c
Roller Bearings	29d, 29e
Fan Belt and Pulley Widths	30
Disk-Clutch Flywheel Housings	31
Cone-Clutch Flywheel Housings	31a
Engine Support Arms—Truck	31b
Poppet Valves	32
Carbureter Flanges	35, 35xa
Flared Tube Carbureter Unions	35a
Flared Tube Carbureter Ells and Tees	35b
Carbureter Throttle Levers	35b
Carbureter Air Heater	35c
Carbureter Throttle-Lever Throw	35d
Flexible Metal Tubing	35d
Hand Starting-Cranks	35e
Magneto Dimensions	36, 36xa
Ignition Distributor Mounting	36b
Flange Mountings for Starting Motors	36d
Barrel Mounting for Starting Motors	36da
Non-Magnetic Magneto Shims	36db
Magneto Couplings-Flexible Disk	36db
Cable Terminals for Generators, Switches and Meters	36dc, 36dd
Cable Terminals for Starting Motors	36e
Cables for Starting Motors	36e
Starting Motor Pinion	36e
Thermostat Connections	37
Clamps and Fittings for Rubber Hose	37
Bases, Sockets and Connectors for Insulated-Return Systems	38xa
Oversize Cylinders	47a
Piston-Ring Grooves	47a, 47b
Instructions for the Installation and Care of Storage Batteries Used in Connection with Electric Starting and Lighting Systems on Automobiles	48, 48a, 48b
Storage Battery Terminal Posts	48xc
Posts for Small Cells	48xc
Dimensions of Lead Batteries for Lighting and for Combined Lighting and Starting Service	48c
Temperature Test of Insulating Materials	

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Data Sheet

of Electrical Apparatus on Gasoline Automobiles 48g
Fuse Dimensions for Electrical Installation on Gasoline Automobiles 48h
Insulated Cable for Gasoline Cars 48i, 48j, 48k, 48l, 48m
Flexible Steel Tubing for Automobile Electric Wiring 48n, 48-o
Rating of Storage Batteries, Electric Lighting Plants 57
Voltage and Capacity Ratings, Electric Lighting Plants 57
Round Pipe Flanges 57a

Voltage and Capacity Ratings, Isolated Electric Lighting Plants

The Stationary Engine and Lighting Plant Division recommended that the nominal voltage of 32 for the 5-kw. normal generator rating in the present S. A. E. Recommended Practice for Voltage and Capacity Ratings of Isolated Electric Lighting Plants, page 57, S. A. E. Handbook, Vol. I, should be omitted. The Division does not believe that the 32-volt rating should be omitted from the 3-kw. size, as it is used frequently for motion-picture operation.

VOLTAGE AND CAPACITY RATINGS

Normal Generator Rating, kw.	[16]Nominal Voltage	Engine and Generator Speed, r.p.m.
½, ¾, 1, 1½, 2, 3	32 or 110	1,200 or 1,800
5	110	1,200 or 1,800

[16]Sixteen cells for 32-volt and fifty-six cells for 110-volt lead batteries.

Cast-Iron Carbureter Flanges

The Division recommended for adoption as S. A. E. Recommended Practice that flanges for cast-iron carbureters be specified as the next larger size for each nominal diameter of opening given in the S. A. E. Standard for Carbureter Flanges, pages 35 and 35xa, S. A. E. Handbook, Vol. I.

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Tire and Rim Division

(Report as adopted by the Society)

Pneumatic Tires for Passenger Cars and Commercial Vehicles

The Tire and Rim Division has recommended that the 33x4½ and the 34x5-in. pneumatic tire sizes be included in the list of S. A. E. Standard regular sizes to meet the growing demand for 24-in. wheels with 4½ and 5-in. tires.

At the meeting of the Joint Executive Committee of the Pneumatic and Solid Tire Divisions of the Rubber Association of America on Nov. 26, 1919, the insertion of the 34 x 5-in. size was approved. At the time of writing this report the 33 x 4½ and 42 x 9-in. sizes are scheduled for consideration and approval at the next meeting of the Committee of the Rubber Association.

The Executive Committee of the Tire and Rim Association at its meeting on Dec. 10, 1919, approved the addition of the 33 x 4½ and 34 x 5-in. sizes and agreed upon the dimensions for the 42 x 9-in. rim.

The addition to the S. A. E. Standard of the 44 x 10-in. size will be considered by the 1920 Tire and Rim Division of the Standards Committee to complete the list of regular and oversize tires in the Standard lineup. The present S. A. E. Recommended Practice for the carrying capacity and inflation pressure of the 9 and 10-in. tires is printed on page 8h, S. A. E. Handbook, Vol. I. All sizes are for straight-side rims.

Nominal Tire and Rim Size		Oversize Tire		Tire Seat Diam. (Rim)	
In.	Mm.	In.	Mm.	In.	Mm.
33x4½	120/610	34x5	135/610	24	610
34x5	135/610	36x6	150/610	24	610
*40x8	200/610	42x9	225/610	24	610
42x9	225/610	.....	.....	24	610

*The 40x8-in. tire is already standard for regular equipment, but is submitted for approval of the 42x9-in. tire as oversize equipment.

Pneumatic Tires for Motorcycles

The recommended practice for pneumatic tire sizes adopted by the Society two years ago was 2¼ and 2½ in. for the BB rim section and 2¾ and 3 in. for the CC rim section. As a result of the experience of the Motor

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Transport Corps here and in France with motorcycle transportation, and owing to the tendency in commercial motorcycle practice being toward heavyweight machines the Tire and Rim Division has carefully reviewed the subject. The motorcycle and tire manufacturers were canvassed to obtain the necessary data for suitable revision of the recommended practice. General opinion among motorcycle manufacturers is that tires should not be smaller than 3 in. as tires under this size have neither the capacity nor wearing qualities necessary for the heavy machines built to-day. The recommendation of a 29 x 3½-in. tire has been considered, but the main objection from the motorcycle manufacturers seems to be that this size tire interferes with the forks and mudguards of the machine unless extensive changes are made in the motorcycle design, to which they are unfavorably inclined.

The members of the Division believe that a definite schedule of motorcycle tire sizes should be adopted, and have recommended the following tire sizes for adoption as S. A. E. Recommended Practice, all sizes to be used on the CC rim section:

Tire Size		Maximum Load		Corresponding Inflation Pressure	
In.	Mm.	Lb. per Tire	Kg. per Tire	Lb. per Sq. In.	Kg. per Sq. Cm.
26x3	75/510	325	147.5	40	2.81
27x3½	90/510	400	181.4	45	3.16
28x3	75/560	325	147.5	40	2.81

The maximum loads and corresponding inflation pressures are already S. A. E. Standard and are printed on page 8h, S. A. E. Handbook, Vol. I.
The present recommended practice for the 28x3 wheel rim and lacing of spokes is printed on page 8-I, S. A. E. Handbook, Vol. I.

Solid Tire Sizes

With the advent of trailers and semi-trailers as an important factor in the automotive industry, there is also a demand for adequate tire standards for this type of vehicle. The Tire and Rim Division is of the opinion that it is unnecessary to have a separate standard for trailer tires as the present standard for pneumatic tires is considered adequate, but it is considered desirable and the Division has recommended that the following solid tire sizes be included in the present S. A. E. Stand-

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ard for Solid Tire Sizes, page 8bb, S. A. E. Handbook, Vol. I.

The Solid Tire Manufacturers' Division of the Rubber Association of America voted to incorporate the proposed sizes in the list of standard solid tire sizes at the meeting on Sept. 24, 1919.

SOLID TIRE SIZES

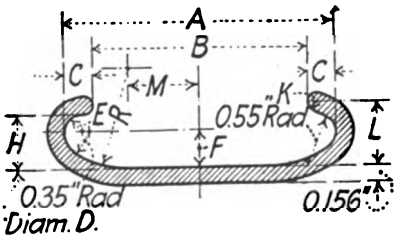
In.	Mm.
36x3	75/762
34x6	150/711
34x7	175/711

Solid Tire Sections

It is recommended by the Tire and Rim Division that the present S. A. E. Standard for Solid Tire Sections be completed by inserting the area of 5 sq. in. for the 3-in. tire size. A canvass of the entire industry indicated almost unanimous approval of this area for the 3-in. size. Since the sectional rubber area should be expressed either with an allowable tolerance or as a minimum it is the consensus of opinion that the column in the printed standard should have the heading, "Minimum Total Sectional Area of Rubber, Sq. In."

Rim Sections and Contours for Pneumatic Tires (Correction)

In the cut for the clincher rim section, page 8ha, S. A. E. Handbook, Vol. I, the 0.55-in. radius is indicated as being to the outside of the rim, whereas it should be to the inside of the rim. It is therefore recommended by the Division that the present S. A. E. Standard for Rim Sections and Contours for Pneumatic Tires be corrected accordingly. This corresponds with the corrected Tire and Rim Association record.



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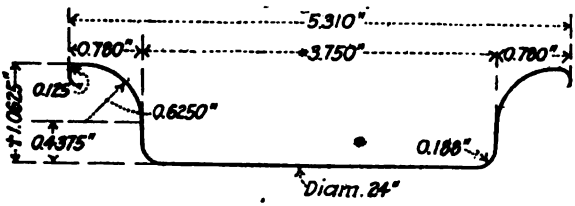
Rim Sections and Contours for Pneumatic Tires
(Extension)

The present S. A. E. Standard, pages 8ha and 8hb, S. A. E. Handbook, Vol. I, does not include a 5-in. rim section. The dimensions given in the accompanying illustration have been worked out and adopted by the Tire and Rim Association and are presented above for adoption as S. A. E. Standard.



Nominal tire and rim size: 34 x 5 in.
Type of rim: straight-side.
Rim diameter: 24 in.
Rim circumference: 75.398 ± 0.047 in.
*Tolerances: plus or minus 0.047 in.
†Tolerances: plus 0.031 in., minus 0.000.

5-IN. PNEUMATIC TIRE RIM CONTOUR

Bolt Equipment for Solid-Tire Side Flanges

The Tire and Rim Division recommends that the present S. A. E. Standard for Bolt Equipment for Solid-Tire Side Flanges, page 8xb, S. A. E. Handbook, Vol. I, be revised to include the 32, 34, 36 and 40-in. tire sizes only, thus eliminating the non-standard 30, 38 and 42-in. solid tire sizes.

Wood Spoke Dimensions for Commercial Vehicle Wheels

The Tire and Rim Division has recommended that dimension *D* in the illustration for wood-spoke dimensions for commercial vehicle wheels, page 8-o, S. A. E. Handbook, Vol. I, and letter *D* in the heading for the column for the nominal spoke size be omitted. The dimensions for *D* (unfinished thickness of spoke between flanges) are not pertinent to the present standard.

TRACTOR DIVISION

(Report as adopted by the Society)

Tractor Belt Speeds

One of the first tractor standards adopted by the Society over two years ago was the belt-speed standard

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of 2600 ft. per min. As there was little uniformity of practice at that time, it was felt that not much more could be accomplished. Over a year ago there was evidence of a strong desire for adequate standardization owing to rapid development of the tractor industry and the relation between factors affecting design, marketing, operation and maintenance common to both agricultural implements and tractors. In February, 1919, a Subdivision of the Tractor Division was appointed which has made a very careful and detailed canvass of the tractor, stationary engine and implement manufacturers to ascertain present practice and to bring the industries into agreement on an adequate and acceptable standard.

It was obvious that the most desirable solution of the problem would be one standard belt speed, but it was also obvious that this would not be practical or satisfactory for a number of reasons. A large thresher having a cylinder speed of 1200 r.p.m. must have a drive pulley of 10 to 12 in. in diameter to have sufficient belt contact to transmit the required power. Consequently a belt speed of 3400 to 3500 ft. per min. is necessary for this class of equipment. A small thresher with cylinder speeds reduced to 800 or 900 r.p.m. for threshing rice or to avoid cracking grain or similar products could not be equipped with a drive pulley large enough for this high belt speed on account of the widening out of the separator directly to the rear of the cylinder. Many power-operated farm implements such as feed grinders, ensilage cutters, shredders, small and medium-sized engines, etc., cannot for many reasons be equipped with pulleys large enough for this high belt speed.

The intention of the Subdivision was originally to propose two or possibly three belt speeds, but a careful analysis of the mass of data obtained warranted the conclusion that it would not be possible or practical to propose less than four belt speeds. In present practice there are from ten to fifteen different belt speeds being used by tractor and agricultural implement manufacturers and it is evident that a reduction of this number of belt speeds to a standard of four speeds is very desirable.

The proposed plan of standardization does not contemplate four standards for every size of tractor, but it is believed will be applicable somewhat as follows:

(1) A belt speed of 1500 ft. per min. is the present standard for stationary engine work, and if used at

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all on tractors would be confined to the very smallest sizes

(2) Belt speeds of 2000 and 2600 ft. per min. would be applicable on tractors in the two-plow or 8-16, 9-18 and 10-20-hp. classes

(3) Belt speeds of 2600 and 3000 ft. per min. would be applicable on tractors of the 10-20, 12-25 and 15-27-hp. and three-plow classes

(4) Belt speeds of 3000 and 3500 ft. per min. would be applicable on tractors of the largest sizes

It is believed that the proposed plan of standardization will reduce the pulley requirements for power-driven farm equipment to not more than two or perhaps three different sizes of pulleys for each machine and to possibly not more than two belt speeds for each size of tractor.

E. A. Johnston, chairman of the Subdivision on Belt Speeds, reported on Oct. 31, 1919, substantially as follows:

REPORT OF SUBDIVISION ON BELT SPEEDS

In the endeavor to arrive at a series of standard belt speeds for power-driven farm machinery, a very thorough analysis of available information was made by the Subdivision. A brief summary of the procedure will be of value in considering the recommendations proposed for adoption.

Machinery Considered The farm power-driven machine groups considered were:

Tractors	Corn Shellers
Threshers	Corn Huskers
Feed Grinders	Hay Presses
Ensilage Cutters	Stationary Engines (small)

Prevailing Belt Speeds Each of the above groups was analyzed in a number of ways. The controlling factors for the standard and special pulley sizes and speeds for these machines are:

Consideration of space, power and revolutions per minute required for clutch and plain pulleys for both power-driven and power-driving equipment with respect to design.

Meeting speed requirements when receiving power from a variety of power-driving equipment, for both stationary engines and tractors, by clutch and plain pulleys.

Meeting speed requirements of the product operated upon by the power-driven equipment.

Consideration of Complexity Consideration was given to the difficulties involved in the adoption of standard belt speeds. It is evident that it is more expensive to meet changes in clutch and plain pulley sizes controlling belt speeds in the tractor group than in any other group. In the thresher group changes involve slippage and interference more than in any other group.

Simple belt speed or pulley changes can be more readily and less expensively made in the last five groups. Due emphasis has therefore been given this phase in selecting the limited number of belt speeds recommended. The experience and volume of output of the various makers of equipment has also been duly weighed. With these ideas in view each group of machines was reviewed by plotting belt speeds against horsepower, belt speeds against pulley sizes, pulley sizes and widths against horsepower transmitted, and belt speeds against machine sizes. From these tabulated data the accompanying chart on belt speeds was made.

In interpreting the chart, line one shows the four recommended speeds of 1500, 2600, 3000 and 3500 ft. per min. As engines do not

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always run at the exact speed and as power-driven machines will operate well at reasonable variations from these definite speeds, as shown by questionnaire answers, lines two and three were plotted with 5 and 7 per cent variations above and below the recommended speeds. It will be noted that the three higher belt speeds thus form an almost continuous series of speeds without overlapping.

Lines four to ten represent the massed speeds obtaining in present practice, thus eliminating the scattered speeds used as the result of inexperience, unsuitable designs or special requirements. It will be seen that mass speeds in feet per minute of the several groups of machines range as follows:

Tractors	2100 to 3150
Threshers	1250 to 1650, 2000 to 3450
Feed Grinders	1400 to 2800
Ensilage Cutters	1300 to 1850, 2000 to 2625
Corn Huskers	2040 to 2100, 2350 to 2500
Corn Shellers	2075 to 2100, 2300 to 2500
Hay Presses	1630 to 1840, 2000 to 2600

There might be some question as to why 2000 ft. per min. was not included in the recommendation, especially since there are so many machines operating at or near this speed. From the chart it will be seen that 2000 ft. per min. is the lower limit for the higher series of speeds, that the average is about 2400 ft. per min., but that tractors and threshers average about 2600 ft. per min. It seemed advisable therefore to select 2600 instead of 2400 ft. per min.

There were 40 replies to the 110 questionnaires sent out or 36.3 per cent.

The replies were quite unanimous in approving the speeds selected as shown by the following percentages, counting only those who gave positive answers or indicated that they would adopt the speeds recommended.

Speed, ft. per min.	Total Number of Replies	Replies Approving of Speeds	Per Cent
1,500	39	37	97.5
2,600	40	39	97.5
3,000	40	39	97.5
3,500	40	38	95.0

Those suggesting additional speeds were 6 out of the 40 or 15 per cent, as follows:

One for 3250 ft. per min. for threshers
Two for 3200 ft. per min. for tractors and ensilage cutters
One for 2000 ft. per min. to meet present practice and ensilage cutters
One for 2000 ft. per min. because range of 1500 to 2600 ft. per min. is too great
One for slow speeds for pumps and cream separators

As to which speeds could be left out, the answers were rather from the view of their individual product.

Speed to be Omitted ft. per min.	Total Number of Replies	Replies in Favor of Omission	Per Cent
1,500	40	5	12.5
2,600	40	1	2.5
3,000	40	2	5.0
3,500	40	7	17.5

As to the probable reduction possible in the number of stock pulley sizes, as a result of standardizing on the proposed belt speeds, the answers indicated the following:

Present Number of Pulley Sizes	Probable Number of Pulley Sizes	Reduction in Per Cent
15	3	80
30	15	50
10	4	60
28	9	68
14	1	93
15	9	40
333	133	40
55	15	73

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BELT SPEED IN FEET PER MINUTE

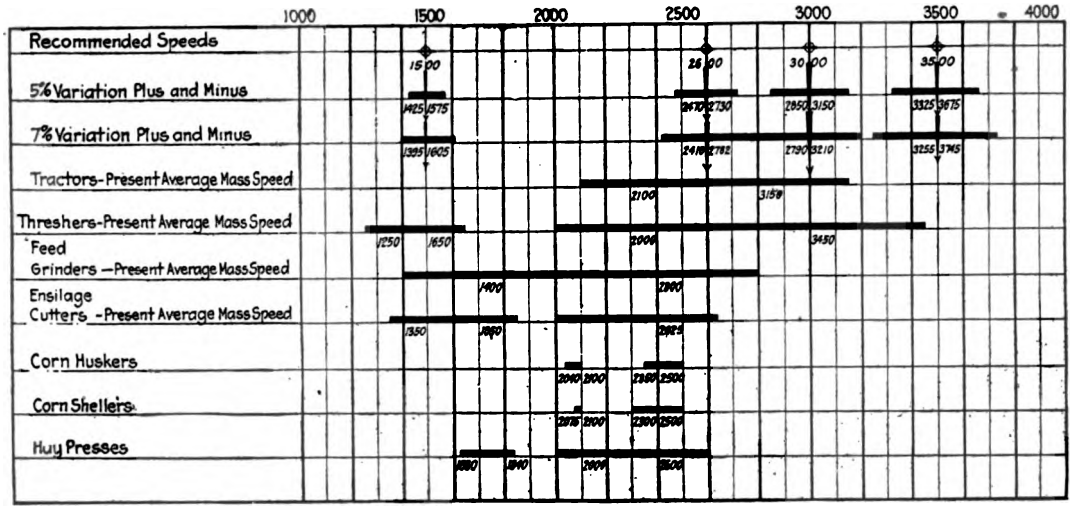

CHART SHOWING PRESENT BELT SPEED PRACTICE

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Belt widths recommended were

4 in. for small ensilage cutters
6 in. for feed grinders and ensilage cutters
7 in. for ensilage cutters
8 in. for ensilage cutters, feed grinders, hay presses and corn shellers

The replies were almost unanimous in approving the series of belt widths proposed, 28 out of 29 or 96.5 per cent being in favor of adopting them.

As to the possible variation allowable in the belt speed, the replies varied in accordance with the type of machine and the product. Replies indicated that from minus 10 to plus 30 per cent of their rated speeds were allowable variations. The mass data varied between minus 5 and plus 15 per cent. This supported the assumption of 7 per cent plus or minus allowable variation in determining the belt speeds.

Replies unanimously favored the adoption of a series of standard speeds.

In reply to the question regarding any special conditions that could not be covered by the proposed belt speeds, there was but one answer dealing with very low speeds in the low-powered machines, which are really outside the transmitted horsepower considered in this report.

Conclusion It is therefore recommended by the Subdivision

That a minimum series of belt speeds for farm power-driving and power-driven machines be adopted as standard.

That, owing to the variety of requirements and the present wide range of belt speeds, future designs of machines and equipment be made to conform to the recommended minimum number of belt speeds.

That in so far as possible present farm power machines be regularly equipped with pulleys to meet these standard speeds.

That 1500, 2600, 3000 and 3500 ft. per min. be regularly adopted as standard belt speeds covering the principal line of farm power-driving and power-driven machines of 10 hp. and over.

That the general large reduction in repair stocks, obsolete sizes required of manufacturers and the smaller variety of replacement parts required by users will effect a considerable saving to all concerned.

That the adoption of the proposed belt speeds need not cause any given manufacturer to discard speeds and pulley sizes either desirable or necessary to his trade but that such cases be considered as special.

That standard belt widths of 4, 6, 7 and 8 in. be adopted.

On Nov. 7, 1919, there was a meeting in the offices of the National Implement and Vehicle Association at which there were representatives of the Tractor and Thresher Division of that Association, the Society of Agricultural Engineers, E. A. Johnston, chairman of the S. A. E. Tractor Subdivision on Belt Speeds and other unofficial S. A. E. representatives. Mr. Johnston's report on belt speeds was discussed and a resolution voted unanimously to recommend to their respective Societies that the belt speeds proposed by Mr. Johnston be adopted as standard.

However, upon later recommendation of the Tractor and Thresher Division of the National Implement and Vehicle Association, belt speeds of 2000 and 3250 ft. per min. were added to the proposal as being favored by the tractor manufacturers in that Association. The extended proposal has been submitted to the members of the Association interested in power equipment, but no action will

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be taken by that organization until the speeds are adopted by the Society or the American Society of Agricultural Engineers.

If it seems advisable later on to add another belt speed or otherwise revise the standard, the subject can be presented again to the Standards Committee and the Society for consideration.

The Tractor Division has therefore recommended for adoption as S. A. E. Standard belt speeds of 1500, 2600, 3000 and 3500 ft. per min. for farm power-driving and power-driven machines of 10 hp. and over as reported by the Subdivision.

Tractor Belt and Pulley Widths

The tractor belt and pulley width standard adopted by the Society in August, 1918, was not completed at that time as there was uncertainty as to what belt width was most desirable for transmitting over 30 hp. As belt widths are an important factor in determining belt speeds the report of the Subdivision includes belt widths, and the Tractor Division has recommended that the present S. A. E. Standard for belt widths be revised to conform to the following proposal:

TRACTOR BELT AND PULLEY WIDTHS

Horsepower	Pulley Width, in.	Maximum Belt Widths, in.
10 to 20	4½ or 6½	4 or 6
20 to 30	7½	7
Above 30	8½	8

Truck Standards Division

(Report as adopted by the Society)

Approval of Existing Standards

The Truck Standards Division has reviewed the present S. A. E. Standards and Recommended Practices and recommends the following as suitable for commercial vehicle practice. Other present S. A. E. Standards and Recommended Practices are referred to their respective Divisions for modification or extension to adequately answer requirements.

	Data Sheet
Adjustable Yoke Rods-Ends	1
Plain Yoke Rod-Ends	1a
Eye Rod-Ends	2
Rod-End Pins	2a
Cotter Pins	2b

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	Data Sheet
Spark-Plug Shells	3
Nuts for Machine Screws	3c
Screws and Bolts	4, 4a
Screw Threads	4c
Lock Washers	5
Square Broached Fittings	7
6-Spline Fittings	7b
10-Spline Fittings	7c
4-Spline Fittings	7d
Taper Fittings with Castle Nuts	7e
Solid Tire and Wheel Diameters, Wheel Circumferences	8
Measuring of Solid Tire Widths	8
Section Dimensions of Single and Dual Solid Tire Wheels	8a
Allowable Tolerances in Felloe Bands	8a
Bolt Equipment for Solid Tire Side Flanges	8xb
Edges of Felloe Bands	8xb
Pneumatic Tires and Rims for Commercial Vehicles	8g
Solid Tire Demountable Rim Equipment for Trucks	8i, 8j
Steel Specifications	9, 9a, 9b, 9c, 9d
Valve Metals	10
Babbitt Metal	11
Bearing Metals	11
Brass Casting Metals	12
Cast Manganese Bronze	12a
Manganese Bronze Sheets and Rods	12b, 12c
Hard Cast Bronze	12d
Gear Bronze	12d
Aluminum Alloys	13
Brass Sheets and Strips	13a
Brass Rods	13b
Tobin Bronze Rods	13b
Non-Ferrous Metal Tubing	13c
Pitch of Silent Chains	14b
Width of Silent Chains	14b
Nomenclature of Roller-Chain Parts	14c
Roller-Chain Dimensions	14c
Round Tension Test-Specimen	15
Flat Tension Test-Specimen	15xa
Flat Tension Test-Specimen	15a
Shock Test-Specimen	15xb

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	Data Sheet
Gray Iron Test-Specimen	15b, 15c
Brinell Hardness Test	15xd
Cold-Drawn Seamless Steel Tubes	16
Steel Bands and Strips	17
Brake Linings	26c
Annular Ball Bearing, Light Series	29
Annular Ball Bearings, Medium Series	29a
Annular Ball Bearings, Heavy Series	29b
Annular Ball Bearings, Tolerances	29c
Annular Ball Bearings, Separable (Open) Type	29ca
Annular Ball Bearings, Extra Small Series	29cb
Annular Ball Bearings	29cc
Roller Bearings	29d, 29e
Thrust Ball Bearings—Steering Knuckle Type	29f
Flat-Face Thrust Ball Bearings, Light Series	29g
Flat-Face Thrust Ball Bearings, Medium Series	29h
Self-Aligning Thrust Ball Bearings, Light Series	29i
Self-Aligning Thrust Ball Bearings, Medium Series	29j
Thrust Ball Bearing Tolerances	29k, 29-1, 29m, 29n
Fan Belt and Pulley Widths	30
Disk-Clutch Flywheel Housings	31
Cone-Clutch Flywheel Housings	31a
Engine Support Arms—Truck	31b
Poppet Valves	32
Carbureter Flanges	35
Large Carbureter Flanges	35xa
Flared Tube Carbureter Unions	35a
Flared Tube Carbureter Ells and Tees	35b
Carbureter Throttle-Levers	35b
Carbureter Throttle-Lever Throw	35d
Flexible Metal Tubing	35d
Magneto Dimensions	36, 36xa
Ignition Distributor Mounting	36b
Bracket Mounting for Generators	36xc
Generator Shaft-End for Coupling Drive	36xc
Flange Mountings for Generators	36c
Flange Mountings for Starting Motors	36d

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	Data Sheet
Non-Magnetic Magneto Shims	36db
Cable Terminals for Starting Motors	36e
Cables for Starting Motors	36e
Starting Motor Pinion	36e
Starting Switch Location	36e
Thermostat Connections	37
Clamps and Fittings for Rubber Hose	37
Electric Bulbs for Ground-Return Systems	38
Electric Bulbs for Insulated-Return Systems	38xa
Electric Incandescent Lamp Voltage	38a
Bulb Sizes	38a
Focusing Length of Incandescent Lamps	38a
Tail-Lamp Glasses	38a
Head-Lamp Socket, Focusing	38a
Head-Lamp Reflectors	38b
Head-Lamp Nomenclature	38c, 38a, 38cb
Head-Lamp Lighting Nomenclature	38d
License Plates and Brackets	39
Location of Numbers	40
Weight of Car	40
Three-Speed Gearshift Positions	46
Four-Speed Gearshift Positions for Motor Trucks	46a
Motor Truck Control-Levers	46b
Oversize Cylinders	47
Piston-Ring Grooves	47a, 47b
Instructions for the Installation and Care of Storage Batteries used in Connection with Electric Starting and Lighting Systems on Automobiles	48, 48a, 48b
Storage Battery Terminal Posts	48xc
Posts for Small Cells	48xc
Storage Battery Compartment	48xc
Insulation Requirements of Electrical Apparatus after Installation on Gasoline Automobiles	48c
Ratings of Lead Batteries for Lighting and for Combined Lighting and Starting Service on Gasoline Automobiles	48d
Addition of Electrical Appliances to Gasoline Automobiles	48d

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	Data Sheet
Specifications for Ground Return Electrical Installations on Gasoline Automobiles	48d, 48e, 48f, 48g
Temperature Test of Insulating Materials of Electrical Apparatus on Gasoline Automobiles	48g
Fuse Dimensions for Electrical Installation on Gasoline Automobiles	48h
Insulated Cable for Gasoline Cars	48i, 48j, 48k, 48-l, 48m
Flexible Steel Tubing for Automobile Electric Wiring	48n, 48-o
Leaf Spring Nomenclature	49, 49xa
Leaf Point Nomenclature	49a
Finish of Springs	49a
Leaf Points	49a
Center Bolts	49b
Rebound Clips, Spacers and Bolts	49c
Frame Brackets	49e
Offset and Resulting Ends	49f
Leaf Spring Specifications	49i to 49t

Four-Wheel Trailer Hitches

This subject was suggested for standardization by trailer manufacturers who appreciate the economic value of having all trucks and trailers interchangeable. Data, obtained from truck and trailer manufacturers showing present trailer hitch practice, were reviewed by a Subdivision acting in cooperation with a special committee appointed by the Trailer Manufacturers Association and a tentative report was made. The report was then sent to truck and trailer manufacturers and their comments obtained. These together with the report were reviewed by the Truck Standards Division and as the comments indicated that the U. S. Government pintle hook was used to a large extent the report was revised to permit its use.

It is not considered desirable to give a fixed dimension from the axis of the drawbar head to the ground because present truck frame heights are approximately the same within required limits. Lost motion between the eye and the drawbar head should be kept as small as possible to prevent the swaying of trailers in operation.

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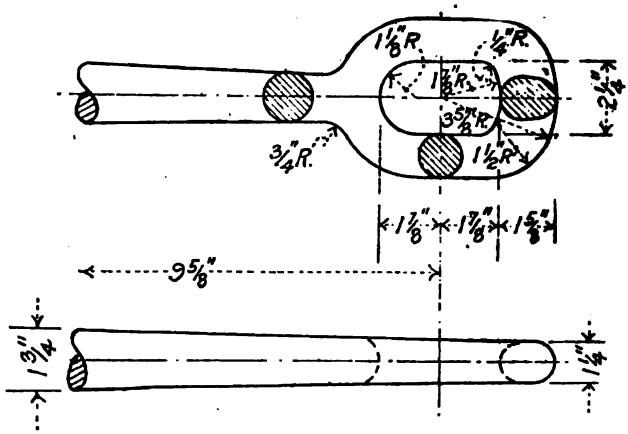

DIMENSIONS FOR PROPOSED TRAILER EYE.

The Truck Standards Division has therefore recommended for adoption as S. A. E. Recommended Practice the following proposal for Four-Wheel Trailer Hitches.

A spring, mounted preferably in the drawbar head,[17] shall be used in the trailer hitch and may be either exposed or enclosed as desired by the manufacturer.

Provision shall be made for chains or other safety devices in addition to the coupling link.[18] A ⅝-in. chain eye clevis with a ¾-in. bolt shall be provided for attaching a safety chain, the clevis to be located directly under the axis of the drawbar head or as near to this position as possible. If placed above the axis it is likely to interfere with operation of the drawbar head.

The axis of the drawbar head shall be located both vertically and horizontally approximately in the center of the frame of the chassis.

The eye[19] for the coupling link shall conform with the dimensions given in the accompanying drawing.

The drawbar-head hook shall be made so as to take the recommended size of eye.

The coupling link shall carry the eye, but when no coupling link is used the eye shall be mounted on the trailer head.[20] The eye shall be free to rotate so that it can be placed in either a horizontal or vertical position. When the drawbar head can be rotated the eye on the

[17] That part which is on the truck.
[18] That part which is between the truck and the trailer.
[19] This size of eye will take the U. S. Government pintle hook.
[20] That part which is on the trailer.

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coupling link or trailer head shall be locked so as to prevent it from rotating.

ATTENDANCE AT MEETING

The members of the Standards Committee and the Society and the guests in attendance were:

Standards Committee Members

Alborn, F. G.
Andrew, F. W.
Aull, J. J.
Bachman, B. B.
Baker, W. C.
Batt, W. L.
Bauder, Paul F.
Bijur, Joseph
Black, Archibald
Blair, B. H.
Bott, George R.
Bradley, C. I.
Brautigan, H. H.
Broege, R. J.
Brumbaugh, A. K.
Burnett, Robert S.
Carlton, C. C.
Chambers, D. F.
Chryst, W. A.
Clarkson, C. F.
Coleman, J. R.
Copland, A. W.
Crane, H. M.
Darrow, Burgess
Diefendorf, W. H.
Diffin, F. G.
Dudley, A. M.
Ehrman, E. H.
Franklin, C. B.
Fretz, E. S.
Gilchrist, C. F.
Gilligan, F. P.
Goldsmith, F. C.
Graham, Walter F.
Gunn, E. G.
Hale, J. E.
Hargraves, A.
Harley, W. S.
Hecox, Major F. C.
Heldt, P. M.
Hess, S. P.
Heywood, Charles E.
Hinkley, C. C.
Holt, J. W.
Hulse, E. G.
Ickes, E. T.
Kalb, L. P.
Kellholtz, L. S.
Keys, W. C.
Knowles, W. H.
Libby, A. D. T.
McCleary, F. E.
McKay, W. A.
McMahon, Harry R.
MacGregor, James S.
Manly, C. M.
Michel, C. A.
Newkirk, W. M.
Norris, G. L.
Norton, W. T., Jr.
Peterson, W. C.
Pierce, H. S.
Sharp, Dr. C. H.
Snow, H. C.
Spicer, C. W.
Stagg, H. J.
Strickland, W. R.
Sweet, E. E.
Thacher, S. P.
Townsend, R. A.
Tubbs, George E.
Tuttle, J. C.
Van Blerck, Joseph
Wall, W. G.
Wells, R. E.
Wood, H. F.

Society Members and Guests

Almquist, K.
Bailey, Charles A.
Bailey, E. W. M.
Bass, M. R.
Baumgartner, W. J.
Bell, John T. R.
Benner, H. W.
Braender, F. J.
Breeze, A. B.
Brehmer, William
Brunner, H. E.
Buckingham, E.
Busby, E. B.
Call, C. A.
Case, F. P.
Clark, E. L.
Clark, Lieut.-Col. V. E.
Coleman, T. E.
Crawford, J. T.
Cunningham, Dr. R. H.
Davies, D. P.
Denyes, H. M.
Deyo, A. K.
Diamant, N. S.
Dickinson, Dr. H. C.
Duckworth, C. H.
Edwards, I. W.
Figgie, H. E.
Flynn, Gregory
Frehse, A. W.
Gage, V. R.
Gillmer, G. W.
Godley, C. E.
Gunster, E. H.
Halbleib, J. C.
Harleman, S. T.
Harrison, O. L.
Hawke, C. E.
Heath, L. J.

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Hoopes, Russell
Horner, L. S.
Howell, J. Bertram
Hutchins, W. H.
Jackson, H. W.
Jaschka, John H.
Johnson, C. R.
Jominy, W. E.
Jones, J. E.
Kaiser, William L.
Kilborn, K. B.
Kliesrath, V. W.
Kononoff, B. A.
Kressler, O.
Lavery, George L.
Laycock, A. M.
Lutes, H.
Lyon, C. L.
McDonald, A. J.
McIntyre, M. M.
MacDonald, H. P.
MacFarland, A. T.
MacKenzie, D.
Margolin, G.
Moskovics, F. H.
Myers, Cornelius T.
Myers, J. L.
Newbold, R. M.
Nielsen, V. A.
Nogle, Byron S.
Northrup, L. M.
Pack, Charles
Pomeroy, T. M.
Quinn, C. J.
Rheinfrank, Eugene
Richards, J. D. F.
Royce, A. C.
Rugg, H. M.
Sargent, G. W.
Schatz, H. A.
Sells, O. P.
Shaffer, R. A.
Shaller, Robert A.
Sivyer, F. L.
Slack, F. W.
Slocum, Frank S.
Smith, F. E.
Sparrow, S. W.
Stern, M.
Swift, William K.
Taub, Alex.
Tavener, C. H., Jr.
Turner, Albert
Udy, I. V.
Veal, C. B.
Verity, C. W.
Ward, L. M.
Watkin, L. M., Jr.
White, H. S.
Williams, L. W.
Woodward, R. W.
Young, Conrad H.
Young, Capt. G. R.
Young, O. W.

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BUSINESS SESSION OF SOCIETY MEETING

An unequivocal success, the 1920 meeting of the Society was declared by the members in general to constitute the most valuable and edifying group of sessions that has ever been scheduled in any half-year of the organization. The intention to make the professional features of broad practical value to all engaged in the various automotive engineering fields was excellently carried out. The interest was closely, even tensely, sustained, particularly on the morning and afternoon of Jan. 8, when the papers and discussion on fuel and research were presented.

The novelty of showing from the speakers' platform indicator diagrams from an internal-combustion engine in operation was much appreciated. The engine was run on various fuels and other substances not generally so employed. Moreover, the meeting was the occasion of the first public demonstration of recently developed high-speed indicators, indicator cards being projected on a screen to make plain the pressure variation in the engine with changing conditions of fuel. Thomas Midgley, Jr., narrated the steps that have been taken in progress in engine indicator work and described the apparatus produced by the company with which he is associated. Dr. H. C. Dickinson demonstrated the scientific indicator developed recently at the National Bureau of Standards. Illuminating papers on engines, aluminum pistons, steam systems, body design and spring suspension were also presented.

The meeting resulted in a better understanding of the elements underlying the combustion of engine fuels. An exposition was given of laboratory methods employed in measuring the rate of flame propagation in engine cylinders and the relation which this bears to engine performance. The subject of mixed fuels was treated briefly. Prof. O. C. Berry of Purdue University reported on tests he had made of wet and dry mixtures. Major G. E. A. Hallett gave information concerning supercharging aeronautic engines. G. A. Kramer, who has been conducting lubricating research work at the Bureau of Standards, discussed the effect on oils in the crankcase

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of dilution by fuel, and outlined methods of preventing and minimizing this effect.

In his scholarly address President Charles M. Manly took as his theme technological knowledge as the basis of all industrial development, ancient and modern, and pointed to many fundamental facts well worth the study of the members.

Financial and Membership Reports

The Treasurer's Report for the fiscal year ended Sept. 30, 1919, showed a gratifying condition, the net income for the period being $49,132.27. The income for the year, including dues, initiation fees and publication, advertising and miscellaneous sales, amounted to $215,-031.07. The operating cost for the year, aside from contingencies, bad debts and depreciation, aggregating $6,281.88, was $159,616.92.

It was reported on behalf of the Membership Committee that in the last calendar year 964 applications for membership had been received, excluding affiliate member representatives and enrolled students, and that of these 830 or about 85 per cent had been approved and had qualified as members. In 1919, taking into account resignations, members dropped for non-payment of dues and the like, the net gain in the Society membership was 688, or approximately 19 per cent. It is considered that the new membership is of a sound nature and constituted of men of a high average of ability and standing.

On Dec. 1, 1919, the total membership of the Society was 4358. Including affiliate member representatives and enrolled students, but not Section Associates, there were on the rolls of the Society at that date 4549 names.

Constitutional Amendments

The principal new business that was brought up at the business session of the meeting was in the form of proposed constitutional amendments, duly submitted in writing and seconded in the manner provided in the Society Constitution as to amendment thereof.

The paragraphs of the Constitution which it was proposed to amend are set forth below, the matter which would be omitted if the amendments submitted were adopted, being printed in brackets, and the new passages that would be substituted in italics.

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CONDENSED BALANCE SHEET AS OF JUNE 30, 1920

Assets		*Liabilities*	
Cash	$36,859.68	Accounts Payable	$22,729.24
Accounts Receivable	42,359.05		
Investments (Book Values)	93,022.50		
Accrued Interest on Investments	3,973.21		
Inventories	1,171.58		
Total Current Assets	$177,386.02		
Furniture and Fixtures	8,118.86		
	$185,504.88		
Deferred Charges	27.89	Reserve	162,803.53
	$185,532.77		$185,532.77

CONDENSED STATEMENT OF INCOME AND EXPENSE FOR THE FIRST NINE MONTHS OF FISCAL YEAR ENDED SEPT. 30, 1920

Income	$185,590.84
Expense	160,269.36
Unexpended Income	$25,321.48

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C 8 Member grade shall be composed of persons [twenty-six] *thirty-two* years of age or over, who by previous technical training or experience or by present occupation are qualified to act as designers or constructors of complete automotive apparatus or their important component parts; or to exercise responsible technical supervision of the production of materials germane to the construction of automotive apparatus; or to take responsible charge of automotive engineering work; or to impart technical instruction in the design and construction of automotive apparatus; or who by reason of distinguished service or noteworthy accomplishment would, in the discretion of the Council, appear to be desirable additions to this grade.

Service Member grade shall be composed of persons [twenty-six] *thirty-two* years of age or over, engaged exclusively by the United States Government, the qualifications for this grade being the same as those for Member grade.

Foreign Member grade shall be composed of persons [twenty-six] *thirty-two* years of age or over, resident in countries other than the United States, Canada, Mexico or Cuba. The qualifications for this grade shall be the same as those for Member grade.

A Member who has become eligible for either the Service Member grade or the Foreign Member grade, may upon written request be transferred to such grade and thereafter, beginning with the next fiscal period, shall pay the annual dues for said grade.

C 10 Junior grade shall be composed of persons who at the time of election are under [twenty-six] *thirty-two* years of age and qualified to fill subordinate engineering positions in the automotive or allied industries, or who are regularly enrolled students at or graduates of a technical school. A Junior Member [may upon reaching the age of twenty-six and] shall upon reaching the age of [thirty] *thirty-two* be transferred to Member or Associate grade, in accordance with the decision of the Council as to which grade his qualifications entitle him.

C 21 The annual dues for membership in each grade and for Student Enrollment shall be as follows:

For Member	$15.00
For Associate	15.00
For Junior (*Under twenty-eight years of age*)	5.00
(*Over twenty-eight years of age*)	*15.00*
For Service Member	10.00

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For Foreign Member	10.00
For Student Enrollment	3.00
For Departmental Member	None
For one Affiliate Member Representative	15.00
For each additional Affiliate Member Representative	10.00

C 29 The affairs of the Society shall be managed by a board of fifteen directors chosen from among its Members or Honorary Members, which shall be styled "The Council." *The Council shall be chosen from among members who have been in the membership not less than two years; and who have demonstrated by effective work as members of Society or Section Committees, or otherwise, both willingness and fitness to devote time and energy to the accomplishment of Society work.* The Council shall consist of the President, the First Vice-President and five Second Vice-Presidents, [representing motor car, aviation, tractor, marine and stationary internal-combustion engineering respectively,] six Councilors, the Treasurer and the surviving Past-President who last held office. *The five Second Vice-Presidents shall preferably be chosen to represent, respectively, motor car, aviation, tractor, marine and stationary internal-combustion engineering; but when men of suitable standing, experience, and proved desire to serve the Society are not, in the opinion of the Nominating Committee, available from each respective field mentioned, two or more from other fields shall be chosen.* Five members of the Council shall constitute a quorum for the transaction of business. The Secretary may take part in the deliberations of the Council, but shall not have a vote therein. The Chairman of the Finance Committee and the Chairman of the Standards Committee may attend the meetings of the Council and take part in the discussion of questions affecting their Committees, but shall not have a vote.

C 34 The Council [may, by a two-thirds vote of the members present, declare any elective office vacant, on the failure of its incumbent for six months, from inability or otherwise, to attend the Council meetings, or to perform the duties of his office, and] *shall declare any elective office vacant in case its incumbent is absent from four successive meetings, or other failure to perform the duties of his office, unless by unanimous vote of the other members of the Council such action is deemed as not being in the best interests of the Society. The Council* shall thereupon appoint a Member or Honorary Member to fill the vacancy until the next Annual Meeting. The said appointment shall not render the appointee ineligible to election to any office.

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The Discussion at the Meeting

PRESIDENT CHARLES M. MANLY:—Under the provisions of the Constitution of the Society, amendments can be proposed now to the constitutional amendments which have just been proposed in written form. I would like to ask whether the wording of C-10, under the change proposed, would mean that a man cannot be elected to full membership until he has passed 32 years?

B. B. BACHMAN:—I believe that is the sense of the amendment.

J. E. SCHIPPER:—I would like to ask if that means that present members would revert to Junior standing under such a rule?

MR. BACHMAN:—It is my understanding that it is difficult, if not impossible, to take away from a man, by action of this sort, rights which he already enjoys. I think, therefore, that it would not be possible to make the amendment effective retroactively.

PRESIDENT MANLY:—This whole matter has come up in connection with the work of the Council Grading Committee on membership applications. My understanding is that what it was desired to do is to overcome difficulty experienced at times due to the fact that the Council has before it applications received from men just over 26 years of age, who have professional training that would justify them in expecting to sometime become qualified for full membership, but who, through lack of experience, or other cause, are not really qualified therefor at the time of application. The idea, therefore, was to enable the Council to elect as Juniors men over 26, who are not fully qualified for full membership, but at the same time have sufficient technical training to make it seem undesirable to elect them as Associates.

I had not noticed before that under the amendment proposed no one could become a Member, that is, a full Member, before reaching the age of 32. I think that is undesirable.

As I stated at the 1919 Summer Meeting, I think that one of the greatest reasons for the activity and the broad point of view of the Society is that we keep our membership relatively young, and I hope the day will not come when we impose too great restrictions in the matter of age.

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W. G. WALL:—I do not quite get the idea of a Junior member having his dues raised at the age of 28.

HERBERT CHASE:—I am not in a position to speak for the Grading Committee, although I have been a member of it for about two years, but I might explain that at the present time a Junior can come in under the age of 26, and remain a Junior with the lower dues until he is 30. The idea of raising the age limit is to enable men under 32 to come in as Juniors who under present practice would, if over 26, be placed as a rule in the Associate grade because of insufficient experience to qualify for Member grade. If this should be done, the income of the Society might be somewhat curtailed because Associates pay $15 a year. It certainly costs the Society more than $5 a year to carry a Junior, whereas Juniors pay only $5 annual dues. It seems reasonable that a man who has reached the age of 28 can well afford to pay $15 dues. A man who pays the low dues of $5 up to the age of 28 really receives as much special consideration as he is entitled to. In other words, at 28 years of age a man should be earning enough to warrant his paying $15 dues, the same as Members and Associates. These are the reasons for the suggested amendments so far as they concern dues and admission.

It should be borne in mind that the Junior grade is intended for junior engineers, whereas the Associate grade is primarily for men not experienced in engineering work. At present an applicant for membership who is over 26 must be placed in the Associate grade, even though his experience is wholly along engineering lines, if in the opinion of the Council he is not yet a full-fledged engineer, or capable of taking responsible charge of engineering work. Such a man naturally objects to being classed as an Associate, even though he can be and often is later transferred to Member grade, when he has become sufficiently experienced. The proposed change would enable a man to remain in an engineering grade as a Junior until 32 years of age, but simply requires that he pay full dues after he reaches the age of 28. It should not be forgotten that the Junior member receives the same advantages of membership as a full member with the single exception that he, in common with Associates, does not possess the privilege of voting and holding office.

C. F. SCOTT:—May I say a word about the suggested change in regard to term of membership before a man

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becomes eligible to the Council? For two separate years it has been my privilege to be a member of the Nominating Committee of the Society, and this change appeals to me very strongly as one that will help materially in guiding the deliberations of the future Nominating Committees. Of course we realize that men of the personality, ability and standing sufficient to make them proper members of the Council, and Vice-Presidents and Presidents of the Society, are extremely busy in our industry, but I think this is a fit time to emphasize again the fact that the nomination to office in the Society is not alone an honor. I fancy that if this phase were a little more emphasized the attendance at Council meetings would be greater. I think this provision should be considered with that in view.

PRESIDENT MANLY:—We desire to get the very best results for the Society; that is all we are after. There may be differences of opinion. Do not have any hesitancy in saying what you think. Let us take an active interest in the matter. This is your Society.

FERDINAND JEHLE:—It seems to me that extending the age limit of Junior membership is in accord with the way we have all felt more or less for some time. It is very difficult to recommend a man for membership who has just passed the age of 26. If he had applied three months earlier, he would have been a Junior or an Associate, whereas if he applies after 26, we must make him an Associate or a Member. If a man is only worth Junior grade to us as a Society, I believe that the Society will be worth to him only Junior grade; that is, I think the dues should be the same whether he is 27 or 29, as long as he is of that grade. Maybe the solution will be to raise the Junior dues to $10, no matter what the age is.

I do not think, however, that because a man is not 32 years old, he should not be eligible to election to membership. I think the men who recommend him, and the Council that considers his election, should exercise their judgment in the matter, whether he should be a Junior member.

PRESIDENT MANLY:—I think that the point Mr. Jehle made is a very good one. I do not want to see it become mandatory that a man really otherwise qualified for full membership in the Society, be excluded therefrom simply because he has not passed the age of 32. The Constitutional provision should be elastic enough to permit the

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Council in its discretion to elect to, and the Grading Committee to recommend for full membership a man of the necessary qualifications.

On the other hand, there is one very important point in this matter, and that is it costs the Society much more than $5 a year to carry a Junior. Now, all of us are the ones who are concerned in the question of how long we are going to carry these men as Juniors, how many of them we are going to carry, and at what age. We cannot say that we are not concerned because we long ago passed the age of 26, most of us are sorry to say, because we are deeply interested in the welfare of the Society. On the other hand, we do not want to make the dues so high for a Junior member that we will not really get the men in, to train them as they should go in the paths of S. A. E.

H. A. GILLIS:—I have listened with interest to the remarks made here about limiting the age. I do not think that the membership of this Society should be limited to any special age. It is not a question of age; it is a question of qualification. Therefore, I think it should be entirely a matter of the opinion of the Council and the members of the Society who are recommending applicants to the Council, whether a man is qualified for full membership or not. I will cite my own case. I am a Member of the Society, but I believe I am not as well qualified for that grade as some men much younger than myself who have joined the Society only recently and are below the age required for full membership.

I think that the question of age limit is a very important one to the Society's welfare. If this Society is not worth $10 a year to any young man who is going along in his profession, I think that the young man is not worth much to the Society.

PRESIDENT MANLY:—This Society is worth much more than the dues to any member. There is no question about that. In fact, the dues that any member pays for his portion of the work of the Society are not commensurate with the value of the work of the Society. The great point that has always come up in connection with fixing the dues has been not so much a question of what membership is worth, as what it seemed possible for people to well afford to pay, and the desire was to make the Junior membership attractive in a financial way. The more money the Society has the better its work can be carried on, the more we can extend it, and the more

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valuable we can make it to every member of the Society.

C. H. YOUNG:—I think that another point on this question should be mentioned. I have had much more to do with the membership of another engineering society than with the Society of Automotive Engineers. In the other Society I am a Member; in this I am an Associate. For the past ten years I have had occasion to talk with many young men, and induce them to become members of the other society, and some of the young men, ranging in age from 26 to 32, were eminently qualified to be full members of that society. I am sure that very many young men of that age are qualified for Membership in this Society. Many have graduated from technical schools between the ages of 21 and 23, and have five or six years' good experience; they are keen, their minds are very active and they can contribute some very good ideas to an engineering society. I think that if this matter is adjusted on the age limit solely, there will be much dissatisfaction on the part of the applicants. I think we do not want that to happen.

PRESIDENT MANLY:—I believe that the proper thing is for all of us to think the question over and get ready for amendments to the written proposals that have been made, to be considered at the Summer Meeting. The matter is now before the Society, and will come up again in due course. The main thing I want you to remember is that we are all concerned in this whole matter.

CONTRIBUTED WRITTEN DISCUSSION

L. S. KEILHOLTZ:—The part of the proposed amendments to which I object is the following:

> . . . but when men of suitable standing, experience and proved desire to serve the Society are not, in the opinion of the Nominating Committee, available from each respective field mentioned, two or more from other fields shall be chosen.

I believe that it is the duty of the Society to build up all the automotive divisions so that men of proper qualifications will be available to represent each as Second Vice-president.

Under the proposed constitutional amendment men representing the motor-car industry would probably be nominated and there would be the possibility of a less

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number of the automotive divisions being represented from year to year officially on the Council. With fifteen members on the Council, at least one should represent each automotive industry.

MR. CHASE:—I was in large part responsible for proposing the amendments, and drafted them in the form submitted. However, they give voice to some pertinent and constructive criticism of the Constitution offered by others.

The objections raised by Mr. Keilholtz to the proposed amendment of C 29 are perhaps natural. Similar beliefs were expressed, I assume, when C 29 was adopted in its present form some years ago to provide for five second vice-presidents. The result has been precisely the condition which the proposed amendments to C 29 and C 34 seek to overcome, namely the Council including in its membership men upon whom honors have been thrust rather than earned by virtue of effective work in and for the Society. In several cases such men have, quite naturally, held the honor so lightly that they have given little or no time to discharging the duties of their office and have attended few, if any, Council meetings. Thus the automotive field they were supposed to represent has not been represented except by other Council members who gave attention to the discharge of their duties.

It has happened in some cases that men of proper caliber were not available in each of the five automotive fields. What we want, as I see it, is a Council composed of men of high standing in the profession, who "have demonstrated * * * both willingness and fitness to devote time and energy to the accomplishment of Society work." With such a Council the Society will be sure to prosper and all of the automotive fields will be better represented, in fact, than if the Council is burdened with members who are representative in name only. I feel sure that, under these circumstances, no field not directly represented will really suffer for lack of representation. Besides, the men who do the committee and other work of the Society are the ones who deserve and should, at least for the most part, be honored by being made officers.

MR. BACHMAN:—With reference to the proposed amendments to the Constitution which were presented at the Annual Meeting by my motion, I would suggest, after having given the matter additional thought, with reference particularly to the comments made by Presi-

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dent Manly, that the amendments as proposed, in their application to C 8, C 10 and C 20, are probably not in a form suited to the best interests of the Society.

In the first place, I feel that in our industry there are a great many men who arrive at a sufficiently high plane in their profession to be entitled to Member grade at a somewhat earlier age than the average for the whole engineering field. At the same time I appreciate, by reason of my past experience, the difficulties encountered, in view of the fact that the Council is prevented from grading a member as a Junior after he has passed the age of 26.

In view of these facts, I am of the belief that the raising of the requirements for Member grade from 26 to 32 years is too drastic, and does not allow for that desirable flexibility which would be a distinct advantage. It is, therefore, my suggestion that in C 8 the present stipulation of "26 years of age or over" shall be amended to read "28 years of age or over," and that C 10 shall read as proposed to be amended, namely, "Junior Grade shall be composed of persons who at the time of election are under 32 years of age * * *." I believe that the second sentence of C 10 should be amended to read, "A Junior member may upon reaching the age of 28, and shall upon reaching the age of 32, be transferred to Member or Associate Grade * * *."

In C 20, the automatic provision for the increasing of dues of Junior members at the age of 28 years, as suggested in the proposed amendment, meets with my approval.

It may seem that my proposed alterations of the amendments are contradictory, but, after careful thought, I have arrived at the opinion that this is not so.

As I propose, under C 9 the qualification as to age for Members, Service Members and Foreign Members shall be a minimum of 28 years. I believe that this is a fair age limit and will not work a hardship by reason of withholding the grade of Membership from men who have, by their work, indicated their fitness.

With respect to C 10, the advancing of the age limit of Junior members from 26 to 32 permits the Council to place in Junior Grade many applicants who are now perforce assigned to the Associate Grade. At the same time it leaves the way open for a man to make application for transfer at an earlier time.

As to the arguments relative to increasing the Junior

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membership fee at the age of 28, while a man is still retained in the Junior Grade, or the condition which will arise when a man between 28 and 32 is assigned to Junior Grade, it seems to me that the differential in initiation fee covers this matter sufficiently. Of course, I feel that the provisions of C 22, relative to the payment in difference of initiation fee at the time of transfer should still hold.

The Constitution Committee of the Society, whose duty it is to consider and make recommendations on all proposed amendments of the Constitution, has made the report given below, in connection with the constitutional amendments proposed at the last meeting of the Society. This report was approved by the Council of the Society at its meeting held on April 9, 1920.

Report of Constitution Committee

Careful consideration was given to the report of discussion had at the meeting of the Society, held Jan. 7, 1920, covering the proposed changes. In addition, letters from various individuals bearing on these questions were read and comments analyzed.

As a result the following suggestions were made:

C 8 should read as originally outlined in the Constitution. In other words, no change in the age limit indicated is desired. The particular reason for this is that it was the opinion of the members present that there were many individuals in the automotive industry, in fact it might be said the great majority, who possessed the fullest qualifications for membership, and who are under the age of 32. This is probably more applicable in the automotive industry than in any other field of engineering activity, and it would be a hardship and an unfairness to not honor a deserving applicant by full membership in the Society.

Under C 10, the age limit of 26 years is recommended to be changed to 30 years, reading as follows:

"....who at the time of election are under 30 years of age, etc."

In addition, the second sentence of C 10 should read as follows:

"A Junior member may upon reaching the age of 28 and shall upon reaching the age of 30, etc."

In connection with these changes it is realized that many arguments in favor of the various age limits mentioned by different individuals exist. While these will

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not be reviewed, it is suggested that the proposed change is more or less in the nature of a compromise, and should meet nearer with the approval of the majority than any of the others which have been suggested.

It should be noted in connection with the foregoing changes that the dues for membership will always be those applying at the time of admission, except as may be modified by amendments later submitted. In other words, a Junior, for illustration, always pays an annual fee of $5.

Under C 29, a modification has been made, and the necessity for which is brought about by the rapidly extending field of activities of the S. A. E. Realizing the manner in which the Council is chosen, full consideration being given to the type of individuals proposed, it is believed that this paragraph should read as follows:

"The affairs of the Society shall be managed by a board of fifteen directors chosen from among its Members or Honorary Members, which shall be styled 'The Council.' The Council shall be chosen from among members who have demonstrated by effective work as members of Society or Section Committees, or otherwise, both willingness and fitness to devote time and energy to the accomplishment of Society work. The Council shall consist of the President, the First Vice-President, and five Second Vice-Presidents, six Councilors, the Treasurer, and the surviving Past-President who last held office. The five Second Vice-Presidents shall preferably be chosen to represent respectively motor-car, aviation, tractor, marine, and stationary internal-combustion engineering."

Note is to be made that the last portion of the recently proposed C 29 has been omitted, and this for more or less obvious reasons. If in the opinion of those empowered to choose there is no representative in a particular field capable of properly representing the Society, elimination of such a representative from the Council in this manner may cause a great deal of unfortunate feeling. As a matter of fact, it is believed that all of the industries now represented are sufficiently big to make it a simple matter to select some individual who is fully up to the qualifications required.

Should a representative be chosen and be found wanting in any particular, his detrimental effect upon Society activities will be, it is believed, much less than would be

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the case were the entire field of industry represented by him ignored.

Constitution Committee:

(Signed) D. L. GALLUP, Chairman.
" W. G. WALL.
" EDWARD ORTON, JR.

ELECTION OF OFFICERS

R. J. Broege, C. B. Veal and F. P. Gilligan were appointed as tellers of election of officers to serve during this administrative year and of Councilors to serve during 1920 and 1921.

They reported that 759 valid and 19 invalid ballots had been cast, the total count on election being as follows:

For President
(To serve for one year)

J. G. Vincent	732
H. M. Crane	3
Joseph Bijur	1
J. G. Utz	1
C. E. Lucke	1

For First Vice-President
(To serve for one year)

J. G. Utz	744
David Beecroft	2
J. V. Whitbeck	1

For Second Vice-President
Representing Motor Car Engineering
(To serve for one year)

W. G. Wall	742
G. A. Weidely	1

For Second Vice-President
Representing Aviation Engineering
(To serve for one year)

G. L. Martin	739
W. B. Stout	1
J. A. Steinmetz	1

For Second Vice-President
Representing Tractor Engineering
(To serve for one year)

H. C. Buffington	743
R. O. Hendrickson	1

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For Second Vice-President
Representing Marine Engineering
(To serve for one year)

C. A. Criqui	743

For Second Vice-President
Representing Stationary Internal-Combustion Engineering
(To serve for one year)

L. M. Ward	742

For Councilors
(To serve for two years)

N. B. Pope	752
A. W. Scarratt	751
F. M. Germane	748

For Treasurer
(To serve for one year)

C. B. Whittlesey	753

Those receiving the largely preponderating numbers of votes were the nominees of the regular nominating committee, no other nominations having been made, and were elected.

Standards Committee Report

The Standards Committee reported for approval at the meeting fifty-one recommendations of Standards and Recommended Practices. The number of Divisions of the Committee reporting was fifteen, as compared with ten and seven at the two last previous meetings of the Society respectively. At the June, 1919, meeting of the Society thirty-three subjects were reported and at the February, 1919, meeting thirty-one subjects.

The 1919 Standards Committee consisted of eighteen Divisions. The total number of S. A. E. Standards and Recommended Practices that had been adopted prior to the 1920 Annual Meeting was 262.

Social Features

The Carnival held on the evening of Jan. 7 measured up to and beyond the great claims made in the announcement of it. It was what it was planned primarily to be, a gathering at which the members could and would become better acquainted.

The 1920 Annual Dinner with over 1600 seated broke all attendance records, and it was as good and satisfactory as it was large.

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ADDRESSES AT THE ANNUAL DINNER

The Annual Meeting terminated on the evening of Jan. 8 with a record-breaking Society dinner. The capacity of the grand ballroom of the Hotel Astor, New York City, was about reached, over 1600 members and guests being present. John Kendrick Bangs was toastmaster. Among the other speakers were J. G. Vincent, then president-elect of the Society; Charles E. Mitchell, president of the National City Co., and Major Arthur Bles of the British Army.

ADDRESS OF JOHN KENDRICK BANGS

Gentlemen, I am no orator, as these other Brutuses are who will follow me. I realize precisely what my position is here tonight. I have been asked to come because of my supreme ignorance upon all the subjects which interest you. I am the one speaker upon this platform tonight who is not going to bore you by talking about things that you think you know more about than the speaker does. I realize that in this difficult gathering in New York, which is always over-congested, and tonight more so than ever, I am nothing more than a sort of traffic cop to keep these intellectual cars and trucks, by whom I am surrounded, moving. I am going to tell them when to go, and if they do not stop when they should, I am going to tell them when to stop.

I have one little thought that I would like to leave in your minds. I will illustrate it by a story of something that I have seen since I saw you gentlemen last, which was almost as inspiring as any experience that has ever come into my life. I have had the rare privilege of visiting the scenes of war, not only in the darkest period of the war, but since the war was supposed to have been finished. I want to say to you that I found a truer Americanism on the other side of the Atlantic Ocean than I have found in the United States of America since I returned. In these days when timid souls are afraid of Bolshevists, when we are afraid to allow a Socialist to sit in the legislature of the State of New York alongside a Tammany official for fear that somebody will get everything that he has away from the Tammany man

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and that he will then begin to work again upon us, I want to tell you something which, if there is any timid-hearted man in this gathering tonight, will reassure him as to the true spirit of America.

Americanism

During my first visit to France in 1918, it was my blessed privilege to try to cheer up the American doughboy, who was face to face with the wickedest enemy that the world has ever known. I went down to the St. Mihiel front and there, one morning, after my first address, there came to me an American soldier-boy, 21 years of age, a private in the ranks, who, simply because of something that I had said that he liked the night before, offered to become my body-servant during the period of my stay there. I did not want an American soldier to be a valet of mine. Considering our respective missions on the other side of the sea, I should have felt it far more fitting for me to get down upon my knees and clean his boots, than have him do so for me. But he left me no alternative than to accept, because he took my uniform, boots, hat, underclothes, everything that I had, and disappeared with them. Even at the front I could not go out and pursue him in such a condition as he left me in. Within half an hour, he had returned with my uniform pressed and my boots polished, and for three days that boy followed me about and smilingly rendered every service that one man can render another. One of my own sons could not have been more solicitous for my welfare.

I naturally inquired about that lad and found that he had been taken by the draft, out of the very dregs of one of our Southern ports. He came from a poor home, he had never had three minutes of education, he had never known the meaning of the word "ideal," he had never known the nice distinction between the words "service" and "servitude," he had never looked upon his father's face, he had not any recollection who his mother was, and he had been a waif and a stray all his days. If this war had not broken out, his natural drift would have been into the embrace of some organized body of thieves, thugs and treasonous ruffians. If he had been in Russia, he might have been a follower of Trotzky and Lenin. The only socially discreditable thing he never could have been is one of these American college professors, of whom we have too many in our institutions of learning who, in these days of social unrest,

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violate the trust imposed upon them by the fathers and the mothers of immature youth, by preaching the ideal of Bolshevism. Bolshevism is not an ideal, but a program of murder, arson, loot and treason, based upon envy, hatred and malice.

The draft caught that boy; took him to an American camp; gave him the first taste of discipline he had ever known; taught him how to hold his head high; taught him why he had a right, as an American, to hold his head high; told him the meaning of the great names of America, of the unselfish devotion to high principle of George Washington, the broad fundamental democracy of Thomas Jefferson, the farseeing vision of Alexander Hamilton, the sense of brotherly love in the heart of Abraham Lincoln, and the everlasting sense of rightness in the soul of Theodore Roosevelt.

They sent him across the sea, and he came and rendered those little services to me, which meant nothing. But the thing that meant a great deal, and which I wish you would etch upon your hearts in moments of despair over American character and institutions, is this: On the morning I left him I went to his captain and said, "Captain, that boy has been perfectly splendid to me; I would like to do something for him. May I give him a little present?"

The captain replied, "Mr. Bangs, I do not want to see you do anything of the sort."

I said, "Captain, I am glad to note that you are a man of nice discrimination in the use of language; I will not let you see me."

And I did not; I took that boy off to one side and said, "Son, you have been perfectly bully to me, and I appreciate it from the bottom of my heart. You have rendered me service which I could hardly expect from one of my own sons, and I thank you for it. Just as you have made me more comfortable here, I would like to make you more comfortable when you go to Paris. Take this and when you spend it, think of me." Then I offered that boy 50 francs.

That lad, who had had no education, no home training, and did not know the difference between "service" and "servitude," pushed my hand back and with a sweet boyish wistful smile and said, "Ah, Mr. Bangs, please do not offer me any money; I do not want to take your money." And then came this beautiful sentence, which in my estimation sums up the whole ideal of American

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character and American intent; he said, "Mr. Bangs, we did not come over here to make money, you know; we came over here to do things for other people." That was the spirit of the American boy in France!

I hope that the next few years will show that this is the spirit of America at home, and that men like you, all true Americans, gathering together, are resolved that they will make the United States not the servant of the world, but the service station of humanity. That is an ideal for Americans to live up to. Then will the departed gods return once more to earth, and their homes will be not upon the Parnassus of Greece but upon the high mountain peaks of our blessed country, America!

ADDRESS OF PRESIDENT-ELECT VINCENT

As I look back over the activities of the Society during the last several years, I think of the difficulties its early officers encountered. They had a great many problems. During their time there was probably very little of what we now know as real cooperation; there was relatively little sympathy with the standardization work, because then many engineers thought that it would militate against initiative on their part. I think you will all realize, if you will look back for a moment, what great results have been attained by the far-sighted policy of the officers of the Society in past years. I need cite nothing more to prove my point than the cooperation that existed throughout the automotive industry during the recent war. I think it is not unfair to us, as engineers, to take unto ourselves the credit for the remarkable cooperation that existed throughout this whole industry in this period. We all know that the automotive industry as a whole was anxious to find out what it could do, and ready to turn its factories upside down to start any work that we, as engineers, said it should do.

I am not sure just how much more difficult the task of the earlier officers was than that of those of us who are to serve now during the greatly increased activities of the Society. It is, of course, true that in electing us you conferred great honor upon us. At the same time you gave us considerable work to do. On behalf of the incoming officers I ask your full cooperation. We know we need it.

I think that everyone will now agree that the Society

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has done a great work in connection with the standardization of parts. This has not in any way reduced initiative. It has, in fact, left the engineer more free to bring about advances in design. We new officers are going to feel very proud if we can follow up the good work that has been carried on by our predecessors. Mr. Manly in his last presidential address outlined much important work to be done. If we can accomplish a considerable portion of that work, we will do well.

Society Growth and Work

The first thing probably that commands our consideration is maintaining the growth of the Society. The membership which is being added is of a high order. We believe that the quality of the membership is constantly improving. When the Society was first organized, it of course was an automobile engineering society. It follows naturally that all the work in connection with the automobile, or what has been called the pleasure car, is further advanced than other work. On the other hand, the truck work has been receiving very close consideration, and, as it has come right up along with the automobile, it is in splendid shape.

One of the new branches of the Society is the Aeronautic Division. You are all familiar with the state of affairs in connection with aeronautic development in this country just before the war. During the war we made great strides, very largely because we had some money to spend on aeronautics, and also because we had practically the whole world to draw upon for information. I wish some of you could have been in my shoes during the war and had the privilege of associating with the very high-grade technical men who came over here from England, France and Italy to teach us something of what they had learned during three years of war. They caught our spirit of cooperation; there was nothing we could ask them upon which they would not give us what information they could. When they first came over there was a distinct tendency among the engineers to be not quite fair with one another. I mean that the English, French and Italians each gave us good information, but they did not agree among themselves as to what should be done. They were all anxious to help, they all did help us a great deal and we can all take a great many lessons from what they told us.

We learned a great deal during the war, but not very

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much has been done since the armistice was signed. What are we going to do about aeronautics now? I realize that that is a very big problem. We must have an air program in this country.

There are other divisions of the Society that are moving along nicely. The Tractor Division has a great work ahead of it. All of the automotive branches can make good use of certain of the standards that have been adopted for some time for car work. Many new standards must, however, be established. We have committees working diligently on this matter.

It is one thing to criticize and another to really accomplish results. Let us all pull together during the coming year and continue our demonstration of what genuine cooperation is. I can only say that, with the rest of the new officers and those holding over, I am going to do the best I can. I hope when we come back here a year hence, we will have accomplished some results.

ADDRESS OF CHARLES E. MITCHELL

You automobile men with your American-made automobiles and American internal-combustion engines made America's name famous throughout the world by their great achievements during the war.

There was a time, not so many years ago, when the bankers of this country did not sympathize very strongly with the automobile men of the United States. We were not altogether on friendly terms. You can remember when bankers were loath to lend on a stock of automobiles on a dealer's floor. Why? Because you were producing "spring hats" that went out of style as rapidly as the seasons passed. You were revolutionizing your product season by season. Today you are not only preaching but practising standardization, that wonderful thing which Mr. Vincent pleads for you to continue, and urges you all to stand for in the coming year. Standardization has done more for the automobile industry from the standpoint of banking, credit and finance, than any other action which has been taken, and I bow to you as the men who have been responsible for that step.

In reading one of Ferraro's books, I found that he compared the conditions which brought about the fall of the Roman Empire with the evolution of conditions that he had observed in America. Ferraro ascribes the cause of the downfall of the Roman Empire to "excessive ur-

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banization"; in other words, the crowding of the people to the cities. He draws the parallel from the conditions he observed in this country and throws out a warning against the decline of America, the fall of advanced civilization from the same cause. If Ferraro is right in his theory, it seems to me that we can look to you men to see that it is only a theory, because I believe that, beyond any other single factor, the automobile and the automotive engineers are going to counteract that force to such a degree that history will not repeat itself in America. You are correcting "excessive urbanization." You make it possible for the man on the farm to enjoy the pleasures of the city to such an extent that he and his children will be more contented, get more out of life, and feel less inclined to gravitate to the city. You make it easy for him to come to the village or the city and to take his family to the "movies"; you make it possible for him to keep in touch with what is going on. You furnish him with a conveyance which enables him to go to his store, or for his doctor, or to visit his neighbor, almost as easily as he could do those things were he living in a city. You make it possible for that man, that great producer of things upon which we live and must live, to enjoy on the farms of these United States the same privileges and conveniences that he would enjoy if he moved to town. If the only danger that we have to look forward to in America is "excessive urbanization," then I look forward without worry, seeing as I do in you men and in your industry, the force which will always take the teeth from that danger.

Economic Reservoirs

Very few bankers have talked to groups of automobile men without in one way or another getting into trouble. One of the reasons is that bankers, for the last two or three years, have continually had to use the words "thrift" and "saving," which seem to be obnoxious to your trade. I believe that you do not hold any different view of thrift than I or the bankers of America hold. We do not mean penuriousness; we do not mean saving here and saving there for the individual gain entirely. When we talk about thrift, we mean setting up in this country economic and commercial reservoirs of wealth which permit the great development of industry and commerce. We want a reservoir of wealth built by saving, from which you can attract the capital that will enable you

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to plan and develop progressively while your established industries are at work on plans long since developed. We want a reservoir of wealth that, through investment, will permit the building of good roads, opening new territories for the tourist and the truck. Certainly your industry will profit by that.

I believe that there is no disagreement between the bankers and you on the proposition that we must have thrift in this country. You want your employees to save something and you encourage them by numerous methods and plans to do so. That is thrift. You want your companies to save some of their profits as they go along. That is thrift. While you desire more production that there may be enough of the things that everybody wants to go around, you must appreciate that something must be saved as you go along; and that is thrift. The great defect in the socialistic theory is that it apparently provides that current production should be used to consume current production, and that there should be no thrift and saving and accumulation of wealth. This is the great fallacy of the Socialistic doctrine. We have statutes at this very time which prohibit thrift from occurring as it should occur. We have an excess profit statute which means that your companies are making lavish and extravagant expenditures that they would not make if that law was not on the books; and such expenditures are made because the United States Government is paying a substantial part of the bill. When the profitable firm has reached a certain degree of profit every expense is considered in the light of the fact that the United States Government is paying a part of the bill of extravagance. You know as well as I that extravagance is supplanting thrift in the commercial enterprises of this country.

There is another law on our books that is taking away the incentive of thrift, the Income Tax Law. It is one law that is causing the men of large incomes in this country to lose the incentive to save. They strive for profit, but they delight in deductible losses. I have seen it in our business for months now. A man comes into the office and says, "I have a loss that I can deduct from my income tax return," and he smiles and is happy. If he comes in and says, "I have a paper profit," he looks as if he were going to weep when he says, "but I cannot include it, for the Government will take it away." We are all working to take losses, but not to take profits

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from which we can practise thrift; and if we are not able to save, we are unable to create that great reservoir of wealth which is necessary to commercial national development.

Unwise Tax Laws

There are three reservoirs of wealth in this country, from which we have to draw for all needs and developments, commercial, national and international. We have the reservoir of institutional wealth, the reservoir of large personal wealth and the reservoir of small personal wealth. In the past few years the first reservoir has been closed to investment demand because, under prevailing commercial activity and general inflation, institutional accumulation was scarcely adequate to meet the regular commercial credit demand. Institutional wealth has not been available for the buying of instruments of credit that run over a long period of time and support the development of this country, your roads, your own factory extensions and improvements. The next reservoir has been closed to investment demand by the income surtax. For more than two years the man of large means has not been buying bonds that are taxable. He could not do so. If he bought a taxable bond at par that carried a 6 per cent coupon, he had to give up in taxes from 50 to 70 per cent of that 6 per cent. It is perfectly obvious that with what was left to him of his income after the tax collector had been around, he would not buy something that would yield him an interest return of 1.8 per cent. He would rather buy tax-exempt securities, or go into a speculation, even though it were what we may call a wild speculation, because, if he lost, 50 to 70 per cent of the loss was the Government's loss, and if he won, the return even after payment of taxes would be substantial. The third reservoir, a broad one indeed but alas also very shallow, has alone been open for investment demand. That great body of small investors has been increasing steadily by the tens of thousands in recent years, but their individual contributions are necessarily small and the adding machine runs up a total entirely inadequate to the country's needs. With this last reservoir alone open to us and with that of large personal wealth closed, we have not been and we shall not be able to support railroad extension and development, public utility extension and development, or the export trade. Let me add that if

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the most favorable railroad bill that could be conceived were to be put upon the statute books, if the most favorable public utility regulatory laws that could be devised were put on the books of every town and county in the United States, we still could not finance those utilities and those railroads so that they could extend and improve and give the best service to this country. This is because the bulk of the financing must be done through fixed maturity obligations for which there is and must be, until our tax laws are revised, a demand totally inadequate to the supply. There are not two railroads in this country, I think I am speaking conservatively, that could finance through stock today, and as for public utilities, none has had the temerity to attempt stock financing in many a long month. In the case of foreign government finance, bonds are the only feasible form of debt to be offered, and we are not able to sell foreign government bonds in sufficient volume to support an export trade because the institutional reservoir and that greater reservoir of large individual wealth are closed. We have only to look to that great body of small investors whose total bond purchases fail to make even a dent in this great foreign situation.

Export trade is the only basic form of demand that we have had in the past year. Railroad commodity demand for improvements has been looked upon year in and year out as barometric of the times. That demand we have not had in 1919. The demand of utility companies for extensions and improvements has likewise been absent. Export demand is the only basic one that we can point to that has been in evidence in the past year or is in evidence today. It will pay us to realize fully the importance of the foreign demand for our commodities and to gage the likelihood of its continuance. I do not wish and do not feel that I am able to discuss the question whether and to what extent foreign countries need our goods. There is a great difference of opinion on that. If you read Sir George Paish, you will think that far-spread famine and international bankruptcy are threatening unless Europe gets our goods by the billions. If you read Mr. Hoover's recent statement, you will see he thinks we do not have to do very much to keep Europe from hunger during the coming year. Authorities differ. Frankly, I do not know whether Europe and the countries that have been devastated by war absolutely need our goods or not. The one

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thing that I am sure of is that we must have the export trade; that trade we cannot get along without.

Export Trade Essential

I have heard the statement made often enough that we are a self-contained country and can get along without any export trade. There never was a more ridiculous statement. Let us take one illustration. In the South they grow 12,000,000 bales of cotton a year. We have facilities in this country for turning into fabrics between 5,000,000 and 6,000,000 bales of that crop. The remainder must move in foreign trade. Now, unless we can find the way to export the rest of that crop and finance that movement, you will see cotton back up in the South, lying in the hands of factors or unsold in the hands of producers, with non-liquidatable cotton paper crowding the banks. Under such circumstances the Southern farmer will, from necessity and not from choice, reduce his producing acreage and curtail his use of labor. He will retrench; his labor will retrench. The commodity buying of the South will be at a low ebb indeed. How long will the now prosperous South continue to buy your automobiles when that occurs? No, we are not a self-contained country today. Given time, say five years, we might, by readjusting the character of production, become self-contained, but as matters stand this year we must have an export trade. You may disagree and contend that the activity of domestic commerce, the degree of domestic buying in all lines of commodities, will keep our factories going and bring a continuance of prosperity; but I answer that the domestic buying movement of today is unbasic, unnatural and ephemeral in character. The money that is being spent so lavishly today is very largely money that has been made easily, during the war and since, and it is being spent just as easily. It is money that was saved and invested in Liberty Bonds during the period when we enforced thrift in this country, and such investments are being cashed in, as the mental burden of the war is lifted. We are having distribution of wealth today, to be sure, as the result of our tax system, but is that small wealth in the majority of cases being saved in any substantial part? No, it is being spent, and we are having a buying demand as a result thereof such as this country has never seen. What will stop it? I see no imme-

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diate stoppage, except as this export demand ceases. Then it would stop rapidly, for our raw products would back up on the farm and in the producing communities to such an extent that from one end of the country to the other you would find a curtailment of buying power that would extend to the city and throughout the land. I say that we must have export trade! But export trade can be had only as it can be financed. How have we done it in the past, and how can we continue to do it?

The balance of trade in our favor in this past year was approximately $4,000,000,000. We established dollar credits for that to the extent of about $1,750,000,000 out of the balance of the $10,000,000,000 fund created by the United States Government for foreign lending. We were able to distribute foreign government securities to the American public to a total of approximately $250,000,000 above the necessary refunding operations and there was left $2,000,000,000, the financing of which we can account for only in one major way. The merchants, the manufacturers and the exporters of this country supplied credits privately, to foreign buyers. Now while those credits were not made directly by banks and did not perhaps find lodgment collaterally in banks, they always affected the banking position because they drew from the quick-asset position of each man or corporation who extended the credits. Either bank deposits were reduced or bank loans were increased in the aggregate of this approximately $2,000,000,000 balance.

Credit Expansion

During the war, and in the past year, we have been leaning heavily upon the Federal Reserve Banking System, a system that has permitted great expansion during and since the war period. Higher prices for everything, high wages, greater stocks of material in transit, larger inventory accounts and increasing receivable accounts, have all shown in that bank statement, week by week, the expansion of the loan and currency accounts and decreasing reserve ratios. But there is a roof even to the credit expansion of the Federal Reserve Bank. There is a point to which the Federal Reserve Bank is not able to go in the expansion of credit in this country. We are gradually, and I am sorry to say not very gradually at that, approaching that point. You have heard the Governor of the Federal Reserve Bank in Washington sound many a note of warning in recent

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months; and that warning must become a commanding note. One thing is certain, your banking system cannot support this year a repetition of the expansion that occurred in 1919 through the export trade balance of $2,000,000,000. It would seem likely that export trade would fall off sharply in 1920. If it does, I ask you to judge whether the present degree of national prosperity can continue? What can be done to save the situation? We can practice individual and corporate thrift, and by paying off our borrowings see to it that the banks are relieved. We can thus make a hole in the credit expansion of the Federal Reserve Bank into which we can tuck additional credits for foreign trade. There are, perhaps, two possible other ways, though frankly I am hopeful of neither. One is to sell the securities of foreign governments or industries to the American public. We have been discouraged about that of late, because we find that the American public generally is not over eager for foreign securities, and we must under existing tax laws eliminate large individual wealth as a buying factor. The total of such securities that we are able to distribute at present makes no more than a dent in the situation. The other possible way is through further lending by the United States Government. But the United States Government, through the office of the Secretary of the Treasury, has announced that it does not propose to make any more loans. I do not know how the Government could make any loans, except as it raised the money by issuing a non-discountable bond of some sort, which I doubt if the country would leap to take in any great volume. I do not believe that the United States Government will and I am not saying it should do it. The way to finance foreign trade is through private capital, but taxation is the block. I believe that our legislators will not reverse their position on personal taxation, for the mass of unthinking voters would scarcely be sympathetic. But it is essential to American commerce that our tax laws be revised.

Things in Washington today are not measured by commercial advantage. In this presidential election year they are measured by the yardstick of political expediency, and except as you and I, through our efforts exerted to the utmost, can change popular opinion and let the legislator who has his ear to the ground know that popular opinion calls for measures that will save the situation, I feel that nothing will be done. And so

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I see troubled waters ahead. I see a time for commercial caution. Mind you, I am not a pessimist; I believe in the American people right down to the ground. I believe in America. I believe that in the end, America, with her great natural resources, wealthier by far than any other country on the face of the globe, with such men as you in the vanguard of progress, and with her great fundamentally sane working classes, aside from those who have claimed to be in that class and who are now "the goods" in the export movement that is taking place from Ellis Island, will "carry on" to a premier position among the nations of the world.

I am not afraid of the future. The future of the next year or two is not altogether clear, but as to beyond that period, I am a great optimist. We may have some depression, something that will bring about a deflation in our prices, a deflation in currency, possibly a deflation in labor, all of which are desirable and probably absolutely necessary things that will put us where we must be, in the leadership of the nations of the world.

ADDRESS OF MAJOR ARTHUR BLES

I will tell you tonight something about the psychological aspect of the great war, and of what we must do to make the sacrifice to which America, in common with all other rightly thinking nations, consented, a useful sacrifice and not a futile waste of life, money and time. I have been told since I came to this country that the American people would not listen to stories of the war now that it is all over. First, it is not all over; any clear-minded person can see that at once; and secondly, I am certain that the desire to forget the war is only a fleeting expression of a passing state of mind, for no country that reveres its great men as this country does, and in the hearts of whose people are enshrined such great courageous citizens as George Washington, Abraham Lincoln and Theodore Roosevelt, can, in its heart of hearts, wish to forget those splendid American soldiers, who, as soon as they were able to do so legally and, as I know from experience, a great many of them did not wait for that moment to join hands with us, went across and helped us to win the greatest victory in the history of the world.

It is an axiom of statesmanship that we must prepare for war if we wish to retain peace, and we know that if

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England and America had been ready for war and had had armies on Continental lines in 1914, the world would have been spared the appalling disaster which overtook it and upset things to such an extent that even now, fifteen months after it is all over, we are no nearer the normal condition of affairs than we were on armistice day. On all sides we have strikes, not as in pre-war days, simply for higher wages enabling men to live under better conditions, but strikes of a clearly revolutionary character, such as the great railroad strike in England organized by German money to upset the life of the country and play into our late enemy's hands, and such as your own longshoremen and miners declared recently, in which the hand of Germany through the I. W. W. is again as clear as the writing on the wall.

Did not Germany imagine in 1914 that the British Radicals and the French Socialists would prevent England and France from putting forth their full effort? And now that we have won, do you think that Germany is attempting to forget the war? I know by experience that she is not, and in spite of her camouflage revolution and the foundation of her so-called Imperial Republic, I know that the men who started the great war are still at her council tables.

War Not Over

Germany is very angry, for she has not only been beaten as no other nation in the world ever was beaten, but she has been humiliated by every clause of the armistice and the Treaty of Peace, and she is not only biding her time for taking her revenge, but she is preparing actively. She will not do it above board and we need look for no outward and visible signs of her preparations, but she is none the less dangerous, and if she can ever make us pay for the humiliation she is undergoing at present, she will not fail to do so and charge us 1000 per cent interest on her outlay.

And yet I am asked to believe that the greatest republic in the world wishes to forget the war now that it is all over. You, yourselves, have not even as yet signed the material instrument of peace. Even if you had, the war will not be over until Germany has given irrefutable proof of her sincere repentance and determination to play straight in the future. Up to the present all indications point in the opposite direction.

To celebrate the return of your armies from France

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you raised a beautiful triumphal arch at the junction of Broadway and Fifth Avenue, bearing on its pediment the inscription, "In memory of those who made the supreme sacrifice for the triumph of the free people of the world and for the promise of an enduring peace," and lower down, names which will make the American soldier glorious for all time; Seicheprey, Cantigny, Belleau Wood, Chateau Thierry, the Marne, St. Mihiel. Now is it fair to the men who at the cost of their lives or their bodily strength placed those names on the flag of your country that you should even try to forget the war? What is the use of raising monuments to them in our cities if we are going to forget them in our hearts? We cannot get away from the essential fact that to forget the war means forgetting those who won it for us.

I am convinced that if the story of the war be told in the right way, divested of all its horrors and misery, but on the contrary clothed in all its splendor of intelligent heroism, no people in the world would be more anxious to hear about the war than the keen, eager-for-knowledge people of this country. By the right way, I mean showing how the war was won by superior brains, what incredible mistakes Germany made in both diplomacy and strategy, and how in every instance advantage was taken of those mistakes, by the Allied leaders, for the cause of right against apparently invincible might. It is of the utmost importance that we should bear this constantly in mind, for it means that if we wish we can maintain our commercial supremacy in the coming fight for the world's markets with the same facility as that with which we maintained our military supremacy on those glorious fields of France and Flanders. And it must not be lost sight of that Germany will wage this new war with just as much bitterness as, and with far greater skill than, she displayed in her fight for military laurels.

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TECHNICAL KNOWLEDGE THE BASIS OF INDUSTRIAL DEVELOPMENT

By Charles M Manly

It is probable that there has never been a time in the history of the world when there has been a more complete disorganization of the fundamental processes of industry than has been experienced by all mankind since the close of the Great War. Just as the conduct of the war was perhaps the greatest illustration that has ever been given of the power of cooperative effort, in which personal and national selfishness was so largely buried while the prevailing public opinion was that nothing would be worth while unless the great peril was overcome, so has the year through which we have just passed been perhaps the greatest illustration of the disorganizing effect of uncertainty and indecision, including a rapid change in the standard or basis of value, accompanied by an attempt on the part of the artisans of the world to secure simultaneously a readjustment of the relative proportion to be allotted to them of the proceeds of industry.

The world seems to have acted very much as a man on a debauch. After spending billions of its accumulated wealth and millions of its man-power, the people in a half-dazed, undecided way have stood around waiting in vain for the distribution of the mythical prizes, apparently fearing that if they became too busily engaged in real work they would not get their share of the spoils of war. This manifestation of personal and group selfishness was a natural and inevitable result of the momentous disturbance of the equilibrium of the standards of value which has occurred, and was bound to occur in connection with such a tremendous expenditure of wealth and man-power. From the beginning of time there has been a constant struggle of all human beings to secure each for himself a larger share of the wealth of the world; and the desire and the struggle have naturally been keener among those having a direct part in the later stages of the production of the increase in the world's wealth, than among those whose activities in connection with the creation of wealth was less direct.

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Fundamentally, wealth is stored or accumulated usable work or that which can be duplicated or replaced only by work. We speak of the wealth of the world having increased from generation to generation. Aside from the change in the standard of value, this increase has been almost entirely one of the accumulated usable work, or of that which would require work to produce an equivalent, where the term "work" is taken in its broadest meaning to cover not merely physical but mental effort directed by knowledge as well. The most basic measure of value is work properly directed by knowledge. The wealth of the world has increased from generation to generation largely because knowledge has enabled a definite amount of human effort to produce an increased amount of the things fundamentally required to sustain life, and to transport these things so as to maintain the proper ratio between supply and demand. The increase in wealth has, I think, been in exact step with the increase in knowledge, for it is only through knowledge that effort can produce an increasingly greater result.

Application of Technological Knowledge

The keystone of this knowledge, that has so directed effort as to enable it to produce this increased wealth, has been, and always will be, technological knowledge. Effort that has had no technological knowledge to direct it to a useful result has added very little to the accumulated wealth of the world. The pyramids have been cited from time immemorial as monuments to man's vanity, but to me they seem to be perhaps the greatest monuments extant to technological knowledge, in that they consumed more human effort than even the digging of the Panama Canal, and yet, through the lack of technological aim or guidance toward a useful result, they are as useless as the Desert of Sahara. Standing at the other end of the row of monuments to technological knowledge are the hydroelectric powerplants of the world, which seem to me to be the greatest illustration possible of the creation of wealth through technological knowledge, for they take energy that nature is wasting in the most profligate manner and convert it into a readily usable form of power, thereby decreasing not only the drain on the world's supply of fuel, but the human effort that would be expended in connection with transforming unmined fuel into a similar amount of power. Undoubt-

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edly the largest portion of the world's increase in wealth has been achieved through the application of mechanical power in place of human, or animal, physical exertion. So long as mankind was confined to the physical exertion of human beings or animals to produce power, the total wealth of the world could change very little, because the surplus beyond that necessary to produce the essentials of subsistence of the men and animals producing the power could never be very great. Perhaps as good an illustration as any of the fact that neither largeness of population nor greatness of natural resources of themselves constitute national wealth, is that of China, a nation with teeming millions of man-power and wonderful deposits of coal, iron and other natural resources, which yet, owing to its lack of technological direction of its industries, is utilizing neither its man-power nor its natural resources in converting these potentialities into real wealth. On the other hand, most of its more than 400,000,000 people exist on what appears to us to be the most meager allowance possible of the fundamental necessaries of life, and yet expend, in securing this, several times the amount of physical effort really necessary. Picture to yourself what a wonderful change would be wrought in these conditions, in even so short a period as 10 years, were the technological guidance of this country, or even of the at present despised Germans, concentrated for that length of time upon directing the man-power of China in the development of its industries.

We naturally feel appalled in contemplating the tremendous loss of man-power, the destruction of materiel and the enormous burdens of national debts which have resulted from the war, especially in the European countries most deeply involved in the colossal struggle. The situation would indeed appear almost hopeless, were it not for the ability of technological knowledge to direct human effort so that, with the aid of mechanical power, not only can the loss of man-power be readily met, but the materiel can be quickly replaced and a large surplus be readily produced with which to discharge the national debts in a very short time. These results, however, absolutely cannot be produced unless and until each of the nations concerned utilizes in the fullest measure the directing power of the technological knowledge of the present day. In this work of regeneration those countries that already possess not only a large body of technologically trained men but also large, undeveloped

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or potential resources, will be the first to replace the lost man-power with mechanical power and create and market the surplus necessary to lift the burden of debt. In those countries where there is a deficiency of technologically trained men, the first concern should be to supply this deficiency by training them, or securing trained men of other nationalities. In those countries where there is a deficiency of natural resources, it will be necessary to utilize technological training to a still greater extent to use more efficiently both the man-power and the natural resources that are available. What can be done in this way was brought very forcibly to our attention by the results achieved by Germany during the war, in utilizing her body of technologically trained men to increase, far beyond what was thought possible, the supply of her man-power, and to make its relatively meager natural resources yield the utmost in food, clothing and other necessary materiel. In fact, in the early stages of the war, the superior ability of Germany along technological lines was very heavily felt by the Allies, and I doubt not that had Great Britain, France and Italy had as relatively large and well-trained bodies of technical men as Germany, the war would have been won by them long before we plunged into it.

There is not the slightest doubt in my mind that, if Great Britain has really as a nation learned the great lesson of the war, that technological knowledge is the keystone of strength and wealth, and applies it not merely by utilizing her present force of technical men to the best advantage, but by greatly extending the training of her coming generations in technological knowledge, she will, with her vast experience in and facilities for commerce, not only very quickly overcome her loss of man-power and wipe out her burden of debt, but also build up an accumulation of wealth that will make her previous credit balances seem insignificant. If she does not both greatly increase her force of technically trained men and utilize them in directing her industries, neither her potential wealth in her colonies, nor her experience in and facilities for commerce, will bring her in the surplus, beyond her necessities, for quickly lifting her burden of debt. Even though Germany, as the price of her wanton folly, has been saddled with a burden of indemnities that is counted as staggering, and she appears to be "hamstrung" to such an extent that many able financiers seriously question

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whether her ability to pay the indemnities is not being greatly jeopardized, still, it is my opinion, that unless all precedents in history are upset, and Germany is prevented from entering freely into the commerce of the world, she will, through the utilization of her technical men in directing her industries, within a few generations, have lifted her burdens of debt and begun the accumulation of a large store of national wealth.

Trend of National Affairs

While technological knowledge is being or should be used in regenerating the other nations of the earth, what is going to be, and must be, the course of affairs in our country? We already have an authoritative prediction of a shortage of not less than 5,000,000 laborers in connection with the industrial activities which must be maintained in this year of 1920, even without allowing for any such normal annual expansion of our industries as we have been accustomed to. Furthermore, it does not appear likely from present indications that the so-called laboring men will exert themselves beyond the point normally expected of them; in fact, it appears that if the laboring men exert themselves beyond 75 per cent of that normally expected of them it will be through some miraculous power operating on their moral consciousness. The answer to this must be that technological knowledge will be immediately applied to a far greater extent even than heretofore in our industries. The lack of man-power must be made up by the still greater use of mechanical power in place of human effort, and still greater strides must be made in efficiently utilizing human effort where mechanical power cannot yet replace it.

Consider for a moment the conditions which exist in this country in connection with such a basic industry as the mining of coal. Every ounce of coal produced in the pit mines, which constitute the largest portion of our producing capacity, is handled at least once by manual labor, with the miner doing this work under conditions where the human effort is expended at less than 50 per cent of the efficiency possible under normal conditions. It has been stated by competent authorities that, by the use of power-operated mechanical devices already available, the cost of mining coal in the pit mines and delivering it to the surface at the mines can be readily

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reduced to one-fifth of the present cost. This means that by the proper utilization of technical knowledge and devices we already possess, at least four-fifths of the man-power now engaged in pit coal mining can be released for supplying the deficiencies existing in other industries. The objection will no doubt be raised that it is the opposition of the miners themselves that has prevented the introduction of these devices in the mines. The answer to this is, I think, that if the devices were installed, and the men who were put to operating them were given part of the saving effected thereby, they would quickly overcome their objections, and the men who were released would very soon, through the demand for man-power in other industries, be found to have gone into other work where the conditions of employment and living are superior to those now existing in the coal-mining industry.

Let us hope, however, that no attempt will be made to bring about such a change by legislation. We have today a bigger surplus of legislation than of any one thing or combination of things. What is needed is a clear, honest statement of the conditions prevailing in such industries, and an equally honest statement of the remedies to be applied, and public opinion will have a quicker effect in causing the remedy to be applied than all the legislation that can possibly be enacted.

The greatest stroke of economy that this country could effect today would be achieved if the majority of the legislators in the country could be replaced by honest, fearless and broad-minded business and professional men who could be depended upon to be free from partisanship and self-interest; even if the salary paid to each of these legislators were $25,000 a year. The "high cost of legislation" is the most expensive thing we have today. No particular group of so-called laboring men are in themselves fundamentally important, any more than any particular lot of capital is fundamentally important, for there is no industrial occupation in which we cannot, in a short time, train a group of men to work efficiently. Capital and labor are both necessary to all industries and both must have a fair return or they will not operate in that industry, and no amount of legislation can coerce them into doing so. The most expensive theatrical performances staged in this country are those of our legislators, and not only do we have to pay for them, although we fool ourselves into thinking

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we have not subscribed for season tickets, but the real cost of the performances has increased at a greater rate than that of any commodity.

The Automotive Field

In our own field of automotive engineering the possibilities seem almost limitless. It is still less than 20 years since the automobile operated by the internal-combustion engine came into real public use, and yet today there are more than 6,000,000 automobiles running on the public highways of this country, and the industry of manufacturing them has grown to third rank in value of product, of the great industries of the country. The horsepower of all these automobiles is more than 120,000,000, or more than 1 hp. for every man, woman and child of the nation. If this total horsepower were in large units, under the management of relatively few men, and these had to be trained specially to control it, the increase in the efficiency of human effort would be only a minute fraction of what it now is with the horsepower distributed into 6,000,000 units, each readily controllable by an operator who has no technical knowledge or training, who has only the most meager experience, and who does not even need to know the whys or wherefores of any part of the mechanism, but merely knows from experience the result of the most simple operations of the controls. With the domestic demand for automobiles today exceeding the supply to a greater extent probably than has been the case at any previous time, and with an almost limitless foreign demand beginning, and appearing likely to grow by leaps and bounds with the awakening of the nations that at present are sleeping or rioting, it would be strange indeed if the industry did not double or treble its present value of output in the coming years.

In the motor-truck division of our field we are commencing to see a real acceleration in the rate at which it is displacing animal power. It is in this division of the automotive field that I expect to see the greatest rate of growth within the next few years. It is also here that some of the engineering problems that are still to be worked out are of the greatest importance. With the railroads hampered as they are likely to be by excessive legislation, and with the cost of labor double what it was only a few years ago, more and more advantage is accruing to motor trucking in competition

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with the railroads. This is especially true in inter-city haulage on the score of cost, aside from the very great advantage which it gives in the decreased cost of packing, lessened damage to the goods from handling, increased speed of delivery and, above all, the certainty of prompt arrival to meet the scheduled requirements. With the several million motor trucks that will be required for this work, as well as for intra-city haulage, rural motor express, and work in connection with farming, mining and the other basic industries, the automotive engineers have yet to do a larger amount of engineering work than they have ever undertaken. This will consist in developing systems of operation and repair and the collection of data in connection therewith, so that not only will the human effort to be expended for these purposes be reduced to the minimum, but costs can be stated just as definitely in advance for these operations as they can for manufacturing. And this work, including that of transportation engineering, is beyond all question that of the automotive engineer, for it is certainly automotive, and I trust that in this Society, which has been noted for its breadth of view as to the real meaning of engineering, there is today no tendency to take a definition less broad than that one which appears to be so apt, and inscribed on the walls of this very building we are now in, reads

> Engineering, the art of organizing and directing men, and controlling forces and materials of nature for the benefit of the human race

In the aeronautical division of automotive engineering we are entering upon the new era of the application of the machines to commercial purposes, and the problems for the automotive engineer to solve in this work are of a higher order and greater in number than in any other division of the field. In the regeneration of the finances of the world, aeronautical machines are, I feel certain, destined to play a most important part. The time limit on human life has not changed appreciably in thousands of years, and is not likely to change in thousands more. Anything, therefore, that saves time is certain to be utilized to the fullest extent possible by mankind. No other known mode of transportation can compare with aeronautical in the speed with which distance can be overcome, and for this reason, if for no other, the development of aeronautical machines in commerce

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is sure to increase at an unprecedentedly rapid rate. In opening up the unexplored, as well as the heretofore known inaccessible regions of the earth, so that technological knowledge can be applied to developing the materials of nature existing there and utilizing them in lifting the great burdens of the war, aeronautical machines will enable a minimum expenditure of capital and labor to convert into quick assets these potential riches that would otherwise remain dormant for several generations. The wealth created by the opening up of our "Golden West" will seem small in comparison with that which will be created by the opening up by aeronautical transportation of the at present inaccessible and unexplored regions of the earth.

In the tractor division of our field there is most important engineering work to be done before the farm can be completely, or even largely, motorized. Flexibility in structure, operation and combination of units and accessibility, ease of repair, service with full interchangeability of parts and ruggedness and durability are all problems in which important advances must be made before the power tractor can win the full confidence of the farmer. While the ideal in all mechanism is the "shark's tooth," which comprises a single moving part, still I do not think that to be successful the farm tractor has necessarily to be made with any fewer parts than other automotive vehicles. But it should have as few parts as is consistent with producing the necessary result. A horse is complicated, and so is a watch, and the farmer uses both and seems to get along well with them, for they are each suited to the work they have to do. But today the farmer's watch tells him that he cannot afford to let a given amount of work take as much time as a horse requires for it, now that labor has become as scarce and high-priced as it is.

In the motorboat field we shall assuredly see a rapid increase in the transportation of freight by power boats with the increasing use of engine-operated loading devices carried by the boats. There is also certain to be a continued increase in the size of the boats and in the amount of power which they will carry. The improvement in the thermal efficiency of the heavier-type engines for boats will undoubtedly lead to the continual replacement of the steam engine in larger and larger boats.

In the stationary gas engine field we are only scratch-

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ing the surface of our opportunities. The increased cost of labor, and the uncertainty of its supply, is bound to result in an enormous extension of the stationary gas engine, enabling one man to accomplish the results heretofore produced by several. This will include not only the farmer and the building contractor, but also the forester, the excavator, the road builder and men in practically every industry where electric power is not readily available.

While we are so busily engaged on all the wonderful developments and extensions of the work of the automotive engineer to facilitate travel, trade and commerce, we must not forget that the nature and selfish ambitions of mankind have not changed to any great extent in the last thousands of years, and that they are not likely to change. We must therefore during our peaceful pursuits prepare for the next war, for there will be another and still others, and the importance of automotive engineering in connection with the wars to come will be so great that we must be as thoroughly prepared as foresight can make possible. The work of our cooperative committee which was appointed by the Council at the request of the Ordnance Department to assist its own engineers in determining plans for the complete motorization of that department, must be given the attention which it deserves. Furthermore, the military and naval side of aeronautics must be kept not only thoroughly abreast of that of the most advanced nation, but as far in the lead as possible. In the next important war not only will the first great blow be likely to come from the air, but such rapid ones, and so many of such great force, will probably be struck that the nation that is not fully prepared aeronautically for land and sea operations will be likely to go the way of the nations of the past.

Increased Society Activity

If we, as a Society, are to measure up fully to the great opportunities that lie before us for advancing the work of the automotive engineer through coordination and dissemination of information in connection with the rapid and large expansions that are sure to come in the many divisions of our field, we must utilize and expand the work of the Sections of the Society and make them living, virile branches of the main organization. In my remarks at the Summer Meeting last June I spoke of

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the great importance to the Society of the work of the Sections, and expressed the determination to aid, in whatever way was found possible, in increasing the professional side of their activities.

One of the greatest impressions left upon the minds of the general public by the war is the power of co-operation, and one of the most important factors in achieving cooperation is organization. Three of the necessary elements that must be agreed upon in advance to enable successful organization to be achieved are aim, scope and plan. I am thoroughly satisfied that we, as engineers, will fall far short of our opportunities in the immediately approaching years, if we do not get into proper step with the tendency of the times and take an active part in securing the general cooperation of the technological engineers of this country. Our aim should be as broad as the definition I have previously quoted of "Engineering," to render the greatest service possible to mankind in general, and our Nation in particular, through the direction of human effort along technological lines and the conservation of our natural resources, and to secure suitable public recognition of the proper status of the engineer. The scope of the organization should change from time to time as the possibilities and exigencies of the situation require. The plan must fit the scope, and must be carefully guarded to prevent over-organization. Both the scope and the plan will naturally be subjects of wide differences of opinion, but if we are equal to our opportunities, we shall certainly be able to agree on suitable compromises, for the very groundwork of cooperation is compromise. The breadth of our mental training and capacity will be largely measured by our willingness to keep away from pettiness.

While we must be most careful to exclude any taint of politics from our objects and our point of view, still we must of necessity take a deep interest in legislation that affects the public welfare along lines in which our technological training makes us especially competent to judge the wisdom thereof, and it is our duty to speak as a body in most definite terms on such matters, and to insist upon being heard. If we are as potent as I believe we are, and have described us as being, in helping to shape the welfare of mankind, we should not, in these important matters upon which we are most competent to speak, hold our tongue for fear of transgressing some unwritten law or code that is based upon the theory that

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the men who never does anything never makes mistakes.

In this matter of shaking off conventions that have hobbled our freedom of expression concerning subjects on which our special training and experience qualify us to speak and act, and of securing proper recognition for what we do accomplish, we shall miss the greatest opportunities for proper recognition that have ever presented themselves if we do not, in connection with the drastic changes which are taking place in industry, seize all available opportunities of demonstrating that not only is technological training and experience no handicap to a business executive, but that it is the best foundation possible for the successful administration of the business of industry. If we cannot keep free from pettiness, this last suggestion is based upon a false premise.

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MIXTURE REQUIREMENTS OF AUTOMOBILE ENGINES

By O C Berry[1]

The paper is based upon the results of tests made by the Purdue Engineering Experiment Station to study the effect upon engine performance of varying the proportions of fuel to air in the mixture, and its object is to determine the variation in the mixture requirements of an engine at different rates of flow of air through the carbureter. The method of conducting the tests is described. The results are plotted in the charts shown and are discussed in some detail, special discussion regarding the effect of speed and load being presented, and the facts brought out by the tests are summarized. In the general discussion that follows, four definite conclusions regarding the richness of the fuel mixture in its relation to the maximum power are stated, and a like number of definite conclusions concerning the richness of the mixture in relation to maximum efficiency are also given. The further conclusions are that it is impossible for a carbureter to supply an engine with the mixture required for the highest efficiency at all speeds and loads, and that the Purdue tests show that the maximum power is obtained when using a wet mixture, the coldest that can be carbureted satisfactorily.

To design any piece of machinery intelligently, it is necessary to know just what requirements will have to be met by the finished product. In the case of the carbureter complete and accurate information on this point is not available. This fact is pointed out in the Second Annual Report of the National Advisory Committee for Aeronautics. This report, in speaking of the object to be accomplished in carburetion, says,

> It must be admitted that there is no convincing experimental proof available from engine tests to establish definitely just what sorts of mixture give the best results in engines; whether, for example, they should

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be constant or variable in proportions of air to fuel, and whether also they should be dry or wet and, if the latter, how much moisture is permissible and in what form.

The art of carburetion is spoken of as just emerging from the experimental stage and previous carbureter designs as worked out on a cut-and-try basis. To the engineers of carbureter manufacturing companies that maintain large experimental laboratories this may seem harsh and only partly true, as these men undoubtedly have considerable information of this character upon which they base their designs. This information is not made public, however, and even the United States Government does not have access to it, as is indicated by the quotation above.

In view of the amount of money invested in the automotive industry, the essential place this industry occupies in our social structure, the great cost of the fuel used each year and the ever-increasing prospect of a serious fuel shortage, it would seem worth while to develop a comprehensive and accurate technology of carburetion and have the information available to all. Recognizing this situation, the Purdue Engineering Experiment Station has been making a study of the effect upon the performance of an engine of varying the proportions of the fuel to air in the mixture.

This paper is based upon the results of these tests and has for its object a determination of the variation in the mixture requirements of an engine at different rates of flow of air through the carbureter. This is one step toward the object to be accomplished in carburetion and enables the presentation of the information desired in the form that will be the most useful to carbureter designers. A careful presentation will be made of the line of thought and the types of test data that have led to the final conclusions. The great number of tests and curves that form the background for the conclusions will be found in the bulletin referred to.

Purdue University Test Apparatus

The apparatus used in these tests was described in a paper[1] presented before the Indiana Section in 1916 in which a portion of the present data was also included.

[1] See S. A. E. Transactions, vol 12, part 1, p. 312.

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This information is, however, so necessary to the purpose of this paper that it is presented again.

The apparatus was designed to give accurate results and to make each test as short as possible, because such a large number of tests are necessary to bring out the desired information. It includes an engine connected to an electrical dynamometer, delicate scales for weighing the fuel, a large diaphragm meter for measuring the air and electrical equipment for starting and stopping the tests. In most of the tests a 4⅛-in. bore by 4½-in. stroke four-cylinder Willys-Knight engine was used. The speed of the engine was read on a tachometer and checked by stop-watch and revolution-counter readings. The torque was weighed by a sensitive scale.

One of the special features was the method of keeping constant the amount of mixture used per minute in each series of tests. It is not easy to set an ordinary butterfly throttle so that it will not move, or in case it does, to reset it in the original position when making check runs. For this reason the throttle was removed and a thin steel plate with a round orifice placed between the carbureter and the intake manifold. The size of the orifice was chosen so that the engine would pull the load at the desired speed when the mixture was properly adjusted. It was found that by keeping the speed of the engine constant and metering the mixture through this orifice, the weight of air used per minute was nearly constant at a constant barometric pressure no matter what the richness of the mixture.

Method of Conducting the Tests

The method of conducting the tests was similar in all cases and will be presented in the form of a description of the first series of tests. Here the object was to determine the effect on the performance of an engine of changing the fuel to air proportions. The orifice placed between the carbureter and the manifold was of such size that when the best mixture was used the engine would develop about half of its rated load at 1000 r.p.m., at which speed the tests were then run.

The engine was carefully warmed up and the carbureter adjusted to provide a good pulling mixture. The air entering the carbureter was heated to 300 deg. fahr., and the cooling water at the outlet to 200 deg. fahr., and the dynamometer scales balanced. The gasoline beaker was then filled and the readings of the various

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test instruments recorded. When the fuel scale came to a balance, the electrical equipment rang a gong and started the stop-watch, the revolution counter and the hand on the dial of the air meter. A weight corresponding to the amount of gasoline to be used was then removed from the scale pan and the attention of the operators was concentrated upon keeping the temperature of the cooling water at 200 deg. and that of the air entering the carbureter at 300 deg., balancing the dynamometer scales and maintaining a speed of 1000 r.p.m.

When the fuel scales again came to a balance, the recording instruments were electrically stopped and the alarm sounded. The various readings were again taken and the test run ended. The weight of gasoline per pound of air in the mixture, the power and the thermal efficiency of the engine were then computed. The first point on each of the curves shown in Fig. 1 could then be plotted.

The mixture was next made slightly richer by opening the gasoline needle, and the brake load was adjusted to hold the speed at 1000 r.p.m. A second test was made under these conditions and another point on each of the curves determined. This was repeated until the engine would begin to miss. The amount of gasoline was then decreased step by step during a series of tests until the mixture was so lean that the engine would not perform properly. This process was repeated, making the mixture alternately richer and leaner until a large number of determinations had been made. The results when plotted gave the desired information with satisfactory clearness.

Discussion of the Results

When a single series of tests is run in a continuous sequence from the lean to the rich end of the mixture range, the plotted points tend to fall in a consistent line and the results seem to have an accuracy that they do not possess. However, if the series is repeated back and forth a number of times, the points will vary somewhat from the original line and show clearly the degree of accuracy being attained. An engine running under what seem to be constant conditions will vary in its performance and the best apparatus is liable to a certain amount of error, so that before any far-reaching conclusions are drawn from the experimental results it is

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desirable to know their limits of accuracy. For this reason the points in Fig. 1 were obtained as outlined above. Since Fig. 1 represents one of the first series of tests to be run, this work was done at the beginning of the entire series of tests before the observers became so expert as they were later, but it is felt that the errors are never greater than are indicated here.

The vertical line in Figs. 1 to 7, inclusive, at 0.067, represents the chemically perfect mixture, or the one in which there is just enough oxygen in the air to burn the fuel without excess of either fuel or air. This value was determined from data in Bulletin No. 43 of the Bureau of Mines. On pages 18 and 19 of this bulletin

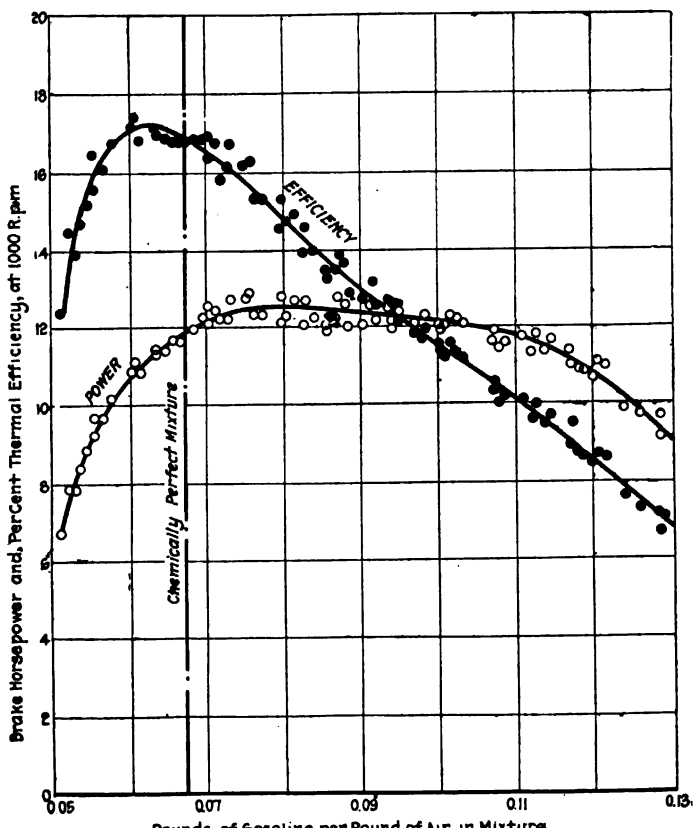

FIG. 1

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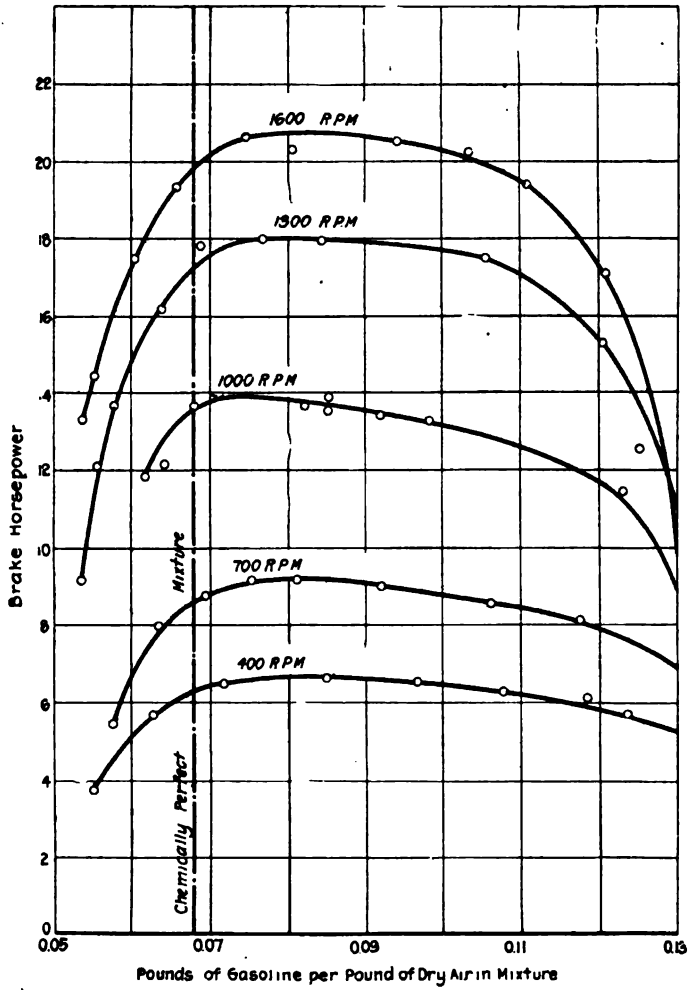

FIG. 2

appear the chemical analyses of several samples of gasoline varying somewhat in specific gravity, such as was used in the Purdue tests. It is there shown that the amount of air required for the perfect combustion of gasolines of this general character is substantially constant.

The curves show that the engine will run with a mixture as lean as 0.05 lb. of gasoline per lb. of air, but

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will not pull well with so lean a mixture. The test log shows that misses frequently occur under this condition, but that the performance becomes better as the mixture is made richer, until at 0.055 lb. every cylinder fires regularly. The highest thermal efficiency, 17.25 per cent, is obtained at 0.063 lb., when the engine is developing 91 per cent of its maximum power with this orifice at 1000 r.p.m. The maximum power is obtained with a mixture of about 0.0775 lb. of fuel per lb. of air, at which point the thermal efficiency is 15.4 per cent. The richest mixture that can be fired regularly is about 0.1275 lb., but the engine will function irregularly with mixtures as rich as 0.135 lb. Nearly full load can be carried

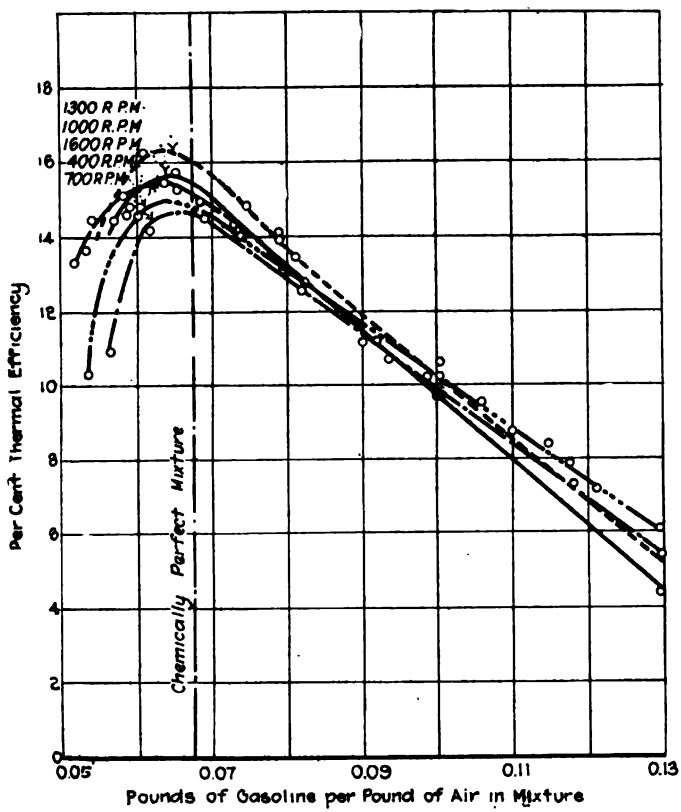

FIG. 8

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with a mixture as lean as 0.065 lb. or as rich as 0.115 lb. In other words, a carbureter can be adjusted with as lean a mixture as can be used to carry full load, and the amount of gasoline can be nearly doubled without greatly affecting the power developed or the smoothness of running of the engine. No missing or irregularity of running will appear, and the chief difference in the performance that can be noted is the more rapid combustion with mixtures which approach the chemically perfect mixture as compared with a very rich or a very lean mixture. A slight metallic knock which disappears as the mixture is made very rich or very lean, is present when a mixture approaching the chemically perfect one is used.

In applying the information obtained from these tests to other conditions, it must be remembered that these results are for half load at 1000 r.p.m., when a warm mixture that was dry as it left the intake manifold was employed. Before applying the conclusions to other conditions one must learn the effect of the load, the speed and the temperature and dryness of the mixture upon the mixture requirements, power and efficiency of an engine.

Effect of Speed and Load

Since the rate of flow of the mixture through the carbureter varies with the speed of the engine, it was necessary to know not only the mixture requirements of the engine at a certain speed, but also the effect of speed upon the mixture requirements. To investigate this point a series of tests was carried out on a Haynes six-cylinder engine. The apparatus arrangement and method of carrying out these tests were the same as in the first series. In this case the engine was run at about half load each time, but at speeds of 400, 700, 1000, 1300 and 1600 r.p.m. Fig. 2 shows the power curves for all the speeds plotted together and Fig. 3, their accompanying efficiency curves.

These tests show that the mixture giving the maximum power is not noticeably affected by the speed, but that at high speeds the engine cannot maintain its power with as much excess fuel or with so lean a mixture as at lower speeds. The latter fact is explained by the slower burning which accompanies very rich and very lean mixtures. The mixture giving the highest efficiency is also unchanged by speed. The practical result of these tests therefore indicates that within the range of mixtures

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giving the best engine performance, the speed does not affect the mixture requirements of the engine either for maximum power or for the maximum efficiency.

In connection with this series of tests it must be admitted that the apparatus is not sufficiently sensitive, nor is the number of tests large enough to demonstrate conclusively that speed has no effect upon the mixture requirements of an engine. However, they do demon-

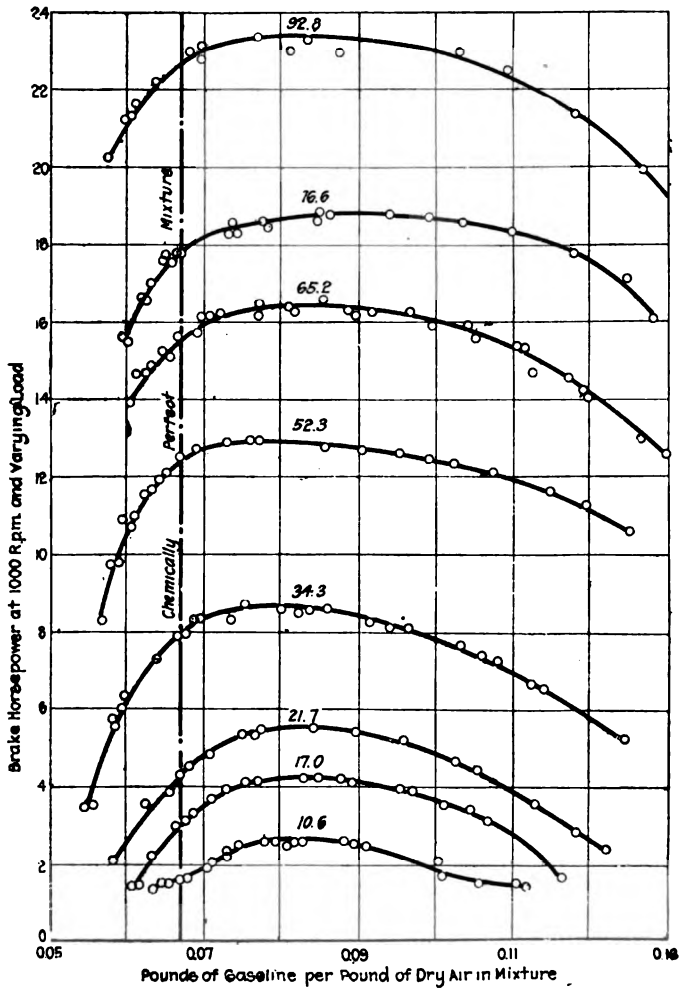

FIG. 4

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strate that the effect is not large and it is my opinion that it is very small, so small in fact that carbureter designers are warranted in proceeding upon the basis that engine speed has no effect upon the quality of mixture desired.

Since the rate of flow of the mixture through the carbureter varies with the load carried by the engine, it was therefore necessary to determine the effect of the load upon the mixture requirements. The third series of tests was designed to investigate this point.

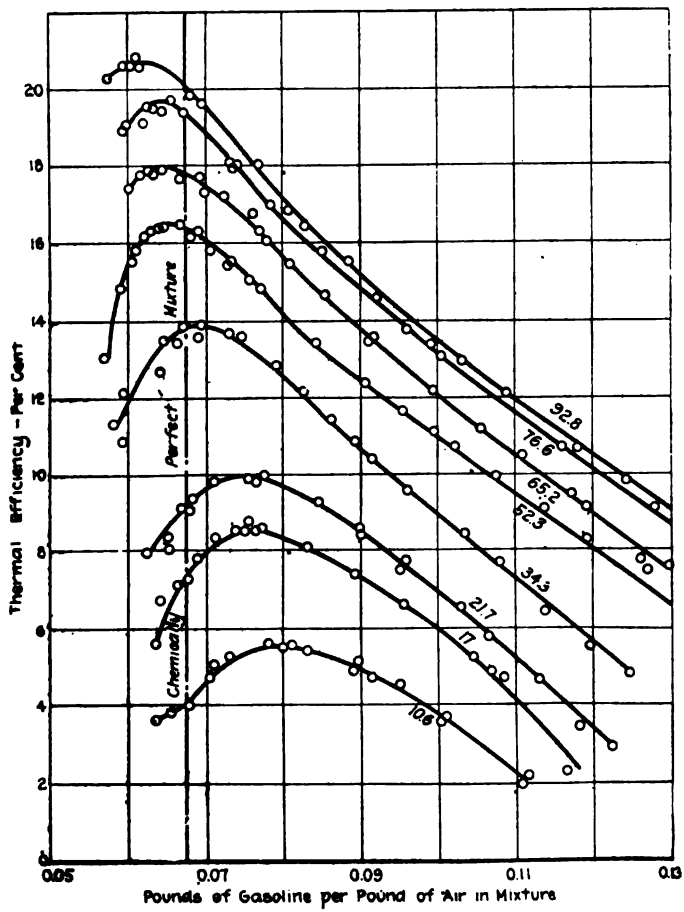

FIG. 5

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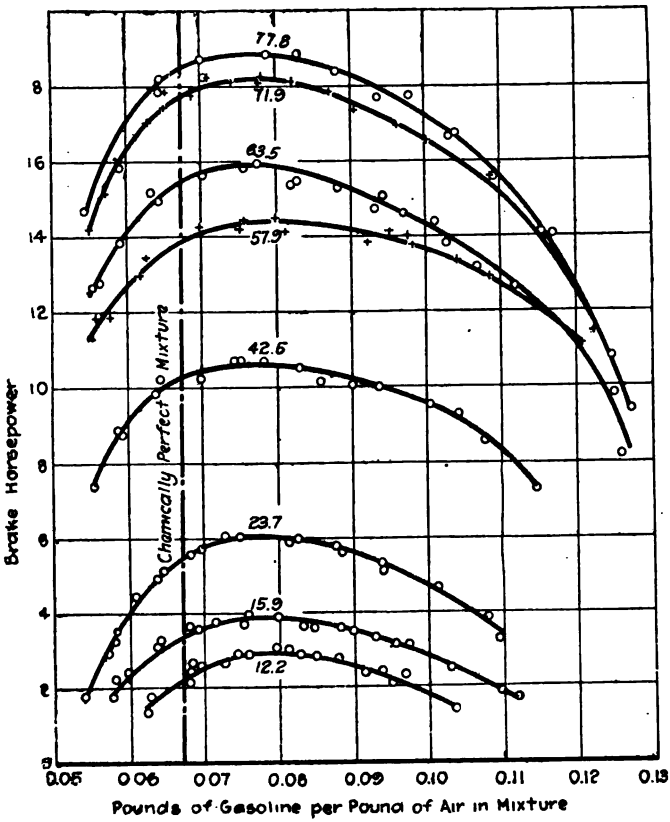

FIG. 6

The apparatus and method of procedure were identical with those just described, except that in this case a separate series of tests was run with each of a series of orifices of different sizes corresponding to different throttle openings. The smallest orifice was just large enough to permit carrying a small load at 1000 r.p.m., the largest one was for full load, and the others were for intermediate ones. By comparing the curves obtained from the different series of tests, the effect on the mixture requirements of the engine of changing the brake load carried becomes very clear. This entire group of tests was first carried out with the temperature of the air entering the carbureter held at 150 deg. fahr., and was repeated later with this temperature

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raised to 300 deg. This was done to determine the relative effect of dry and wet mixtures as affecting the results and the conclusions drawn from the tests. Both series of tests are presented here.

Fig. 4 shows the power curves for the tests made with 150 deg. air and Fig. 5, the corresponding efficiency curves. Fig. 6 shows the power curves for the check runs with 300 deg. air, and Fig. 7, the corresponding efficiency curves. These tests bring out the following facts:

(1) The mixture giving maximum power does not vary materially with the brake load carried, but remains constant at about 0.0775 lb. of gasoline per lb. of dry air

(2) At light loads, the engine will not operate well with as wide a range of mixtures as it can use when carrying more nearly its full capacity

(3) The mixture giving the maximum thermal efficiency becomes leaner as the brake load is increased, especially between no load and half load. At light loads the mixtures for maximum power and efficiency coincide at 0.0775 lb. of gasoline per lb. of air, while at full load the best efficiency accompanies 0.062 lb.

General Discussion of Results

In the bulletin referred to a number of conclusions are drawn relative to the richness of the mixture for the maximum power and efficiency. On account of lack of space the reasons for all of these conclusions cannot be given, but the conclusions themselves are of considerable interest and will be presented.

Regarding the richness of the mixture in its relation to the maximum power, the following conclusions seem warranted:

(1) There is a very definite range of fuel mixtures that will give the maximum power in any engine, when the temperature of the mixture is such as to make proper carburetion possible. This range extends a little above and a little below 0.0775 lb. of gasoline per lb. of dry air

(2) The engine requirements as to the richness of the mixture for maximum power production are not appreciably affected by

- (*a*) The speed of the engine
- (*b*) The load carried by the engine
- (*c*) The load of the carbureter used[a]
- (*d*) The type of the engine used[a]

[a] Unless through the items listed under (3) page 125.

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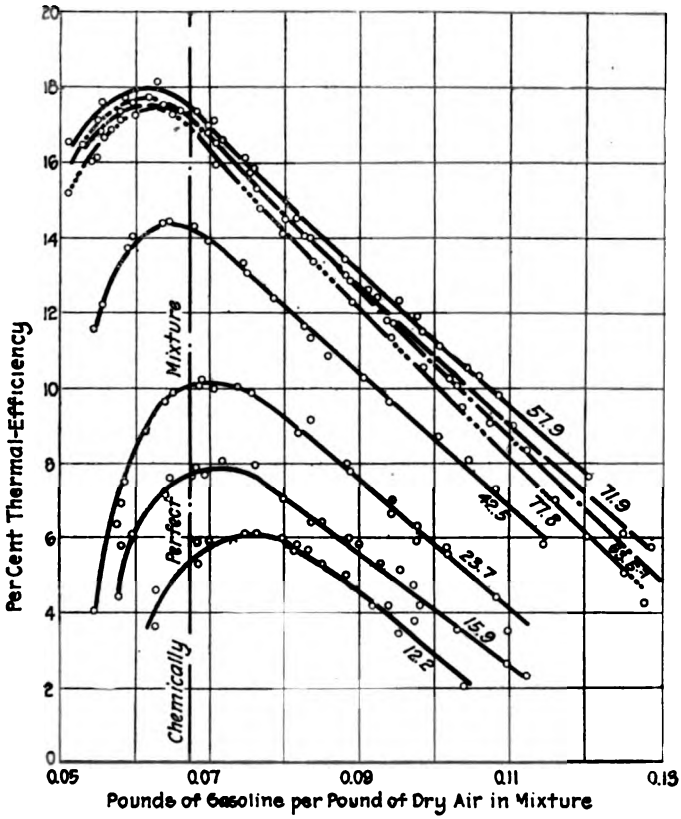

FIG. 7

(3) The engine requirements as to the richness of the mixture for the production of the maximum power are affected by

(*a*) The dryness of the mixture

(*b*) The quality of the fuel used

(*c*) The equality of mixture distribution to the different cylinders

(*d*) The uniformity of the mixture of the fuel and air in each cylinder

(4) The range of mixtures through which approximately full power will be produced is very wide, the richer mixtures containing more than twice as much fuel as the leaner ones. This range will vary

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somewhat with the brake load carried, being widest at about half load, where with a dry mixture the engine will fire regularly when consuming 0.055 lb. of gas per lb. of air, pull substantially maximum load between 0.065 and 0.115 lb. and continue to fire regularly up to 0.1275 lb. At full load this range is diminished slightly, but at a very light load it is narrowed for regular firing to between 0.070 and 0.095 lb. A study of the curves in Figs. 4 and 6 makes these facts evident

In all cases the figures quoted are for warm, dry mixtures. If the mixtures are cold and wet the figures will be higher, and the engine will not run with some of the leanest mixtures quoted here unless both engine and mixture are hot.

A question may well be asked as to why it is that the maximum power is produced when excess fuel is present, rather than with a chemically perfect mixture. Two factors are probably responsible for this. In the first place the fuel is never quite uniformly mixed with the air, so that when the total air and gasoline are in proper proportion some parts of the mixture are too lean. The main reason, however, is the fact that when a rich mixture is used the hydrogen tends to burn in preference to the carbon, leaving a deposit of carbon in the cylinder. The effect of this upon the power of the engine may be understood by its analogy to the case of the combustion of methane, CH_4. The combustion of 1 cu. ft. of methane requires 9.56 cu. ft. of air and will produce, at 32 deg. fahr. and 14.7 lb. pressure, 1072 B.t.u. To burn the hydrogen out of 2 cu. ft. of methane will require the same amount of air but will produce 1392 B.t.u. Thus more power will be produced with the richer mixture.

In respect to the richness of the mixture in its relation to maximum efficiency, the following conclusions seem warranted:

(1) There is a very definite richness of fuel mixture that will give maximum efficiency under given running conditions of the engine

(2) The requirements of the engine as to the richness of the mixture for maximum efficiency are not materially affected by
   (*a*) The speed of the engine
   (*b*) The type of the carbureter used[4]
   (*c*) The type of engine used[4]

[4]Unless through the items listed under (3) on page 125.

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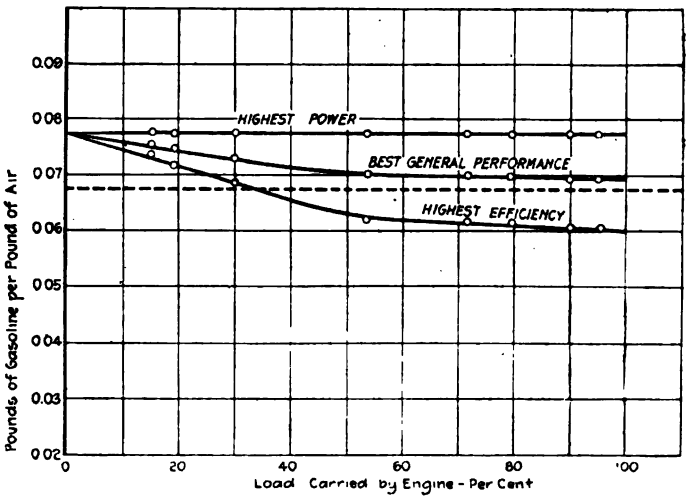

FIG. 8

(3) The requirements of the engine as to the richness of the mixture for maximum efficiency are affected by
   - (*a*) The brake load carried
   - (*b*) The dryness of the mixture at the end of the compression stroke
   - (*c*) The type of fuel used
   - (*d*) The uniformity of the distribution of fuel to the various cylinders
   - (*e*) The thoroughness of the mixing of fuel and air in each cylinder

(4) The range of mixtures through which approximately the highest efficiency is obtained is very narrow. This is in distinct contrast to the situation relative to the generation of power and the smooth running of the engine, and accounts in part for the fact that many engines run well and develop good power but prove very inefficient in their use of gasoline

The effect of the brake load carried upon the mixture requirements of an engine when warm dry mixtures are used is represented graphically in Fig. 8. In developing these curves Figs. 5 and 6 were referred to and the mixture giving the maximum efficiency at each brake load was estimated. These brake loads were then expressed as percentages of full load and the lower curve on Fig. 8 plotted to show how the richness of the mix-

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ture for the highest efficiency varies with the load carried. The mixture for highest power is a straight line at 0.0775 lb. The middle curve is arbitrarily drawn half way between the other two and is called the mixture for the best general performance. It represents a mixture that will give substantially the maximum power and at the same time approximate the highest possible efficiency. These curves represent the requirements of the engine at a constant speed.

In all of the previous discussion attention has been centered on the requirements of the engine and the conclusions drawn have been modified by the different speeds and loads at which the engine was operated. In designing a carbureter, however, these conclusions must be interpreted in terms of cubic feet of air delivered per minute. Changes in the speed of the engine and the brake load it carries simply vary the rate of flow of the air through the carbureter. Beginning at the smallest flow rate that the engine will require, it is obvious that the volume of air required per minute may be increased either by increasing the brake load at a constant speed, or the speed at a constant brake load or by increasing the load and the speed together. Thus the same engine may require 20 cu. ft. of air per min. with a wide-open throttle at 400 r.p.m. or running light at 1500 r.p.m., yet so far as the carbureter is concerned there will be no change in rate of flow or the mixtures furnished under these widely different conditions. The mixture required for the maximum efficiency of the engine under these two conditions is, however, quite different. With a wide-open throttle at 400 r.p.m. Fig. 8 shows that 0.062 lb. of gas per lb. of air will give the greatest efficiency, while at 1500 r.p.m. and no load, 0.0775 lb. of gas per lb. of air is the most efficient mixture. Thus it is impossible for a carbureter to supply an engine with the mixture required for the highest efficiency at all speeds and loads.

Fig. 9 shows the variation in the mixture requirements of an engine for the highest efficiency, in terms of the rate of flow of the air through the carbureter. In this case the engine has been assumed to have a maximum requirement of 93 cu. ft. of air per min. and a speed range of 200 to 2500 r.p.m. This will make the air required for 200 r.p.m. at full load about 9 cu. ft. per min. and 2¼ cu. ft. per min. at no load. Under the latter condition the mixture required for

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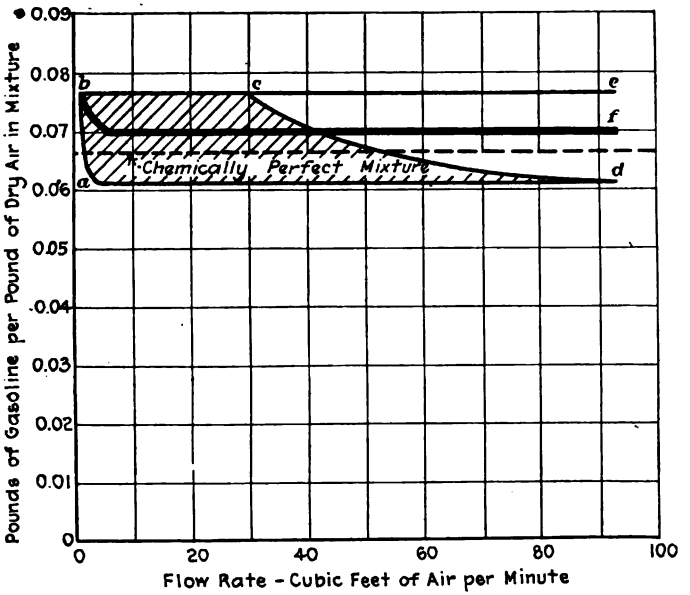

FIG. 9

the highest efficiency is 0.0775 lb. This point is marked *b*, Fig. 9. As the speed increases at no load, the rate of flow of the air increases and the mixture for maximum efficiency remains the same. Thus *bc* represents the mixture requirements at no load between 200 and 2500 r.p.m. From *c* to *d* the rate of flow is increased by increasing the brake load at 2500 r.p.m. The shape of the curve is taken from Fig. 8. The curve *ba* is similar in shape to *cd* and represents the change from 200 to 2500 r.p.m. at full load. Thus the shaded area *abcd* shows how much the mixture requirements of the engine may vary at any rate of flow, when the maximum efficiency is attempted.

The mixture requirements for the best general performance may also be indicated on this graph, *bce* representing the mixture for the maximum power, and *bf* that for the best general performance. In connection with *bf* several points should be noted. There is no combination of speed and load where this mixture will not fire regularly if it is warm and dry. With a wide-open throttle this mixture will give substantially the maximum power and at the same time nearly the best

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efficiency. In the average touring car the engine runs most of the time at approximately one-third to one-half of its full load. Under these conditions the proposed mixture will actually give the highest possible efficiency, as is shown by Fig. 7. A curve similar to *bf* can be drawn for any engine and the carbureter that follows that curve will be as nearly ideal for that engine as is possible.

All of the foregoing conclusions have been based upon tests where 58 deg. Baumé gasoline was used and the mixture was warm enough to be dry. In applying them to other conditions due consideration must be given to the effect of the fuel used and the temperature of the mixture, upon the mixture requirements of the engine. The Purdue tests show that the maximum power is obtained when using a wet mixture, the coldest one that can be carbureted satisfactorily. Under these conditions the highest power is obtained with a mixture containing 0.08 lb. of gas per lb. of air, and at half load the mixture for the greatest efficiency was raised from 0.063 to 0.067 lb. These figures will therefore represent the magnitude of the variation in the mixture requirements of an engine that can be caused by the temperature of the mixture, when the engine is warm enough to run well. When the engine is very cold still richer mixtures are necessary. The excess fuel required will vary with the quality of the fuel and the temperature of the engine. In the very coldest weather the mixture can scarcely be made rich enough to start a cold engine with 58 deg. gasoline.

The results reported here are merely a beginning toward defining the object to be accomplished in carburetion. The automotive industry will do well to recognize the importance of this problem, and the desirability of developing a comprehensive technology of carburetion.

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AUTOMOBILE BODY DESIGN

By William Brewster[1]

The author first considers the style and arrangement of the seats, the position of the rear axle as affecting the rear kick-up in the chassis frame, and the position of the rear wheels as determining the distance from the back of the front seat to a point where the curve of the rear fender cuts across the top edge of the chassis frame. The location of the driver's seat and of the steering-wheel are next considered, the discussion then passing to the requirements that affect the height of the body, the width of the rear seat, and the general shape. The evolution of the windshield is reviewed and present practice stated. Structural changes are then considered in relation to the artistic requirements, as regards the various effects obtained by varying the size or location of such details as windows, doors, moldings, panels, pillars, belt lines, etc., and the general lines necessary to produce an effect in keeping with the character of the car. The design of the wings or fenders, the weight, producing effects of light construction, and the use of aluminum are also considered, the conclusion reached being that the design of the highest type of automobile body should always be based primarily upon a high degree of practicability.

An automobile body must be considered from two different viewpoints, its suitability for the work required of it and its appeal to the eye. All designs should first be based upon practical needs and construction. The first consideration should be the number of passengers to be carried and the way in which they are to be arranged; in other words, the style and arrangement of the seats. These factors determine, or should determine, the length and width. The wheelbase is a controlling factor in respect to length, and affects length in two ways.

The position of the rear axle governs the position of the rear kick-up in the chassis frame; this, to a large extent, determines the position of the rear seat. If this seat is put too far to the rear it is impossible to provide a flat floor directly in front of it, due to interference with the kick-up of the chassis frame, and unless a flat floor is provided it is impossible to sit with one's feet in a natural position, thus detracting from the comfort of

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the car. It may also bring about an added defect by causing the rear seat to overhang the rear axle to such an extent as to cause bad weight distribution and thus produce bad riding qualities.

The position of the rear wheels also determines a very important dimension, that of the distance from the back of the front seat to a point where the curve of the rear fender cuts across the top edge of the chassis frame. The doorway is essentially to make the body easy of access. If the curve of the rear fender comes far enough forward to require cutting into the bottom of the door, then the space at the bottom of the doorway, for entrance, is curtailed to such an extent that sometimes only agile persons can use it conveniently. Further, a cut in the door at this position can in some cases prevent the lowering of the door window to be flush with the framework of the body, which is generally desired and absolutely essential on any landaulet. Realization of this fact has frequently resulted in the front compartment being unduly restricted, causing discomfort for the driver. The increasing popularity of the closed body is probably having an effect on chassis engineering, because it is noticeable that there is much less space wasted under hoods than formerly. Opinions will of course differ as to the exact amount of space which should be given, but the position of the driver is really controlled by dimensions that are determined entirely by chassis construction and to which the designer of the coach work is obliged to conform.

First, the driver must sit so that the pedals can be operated without strain. This really determines the position of the driver's seat. The steering-wheel should come where it is convenient for the hands to reach it. A very common fault is that the steering post is too short so that it comes where a tall man's thighs will strike it, while if the bottom of the wheel comes in line with the joint of his body with his thighs, almost any size of person can be made comfortable without taking up undue space behind the wheel. The rim of the wheel nearest the driver, on an ordinary upright post measuring about 25 in. from the bottom of the steering wheel to the top of the chassis frame, should be about 27 in. from the pedals. A comfortable distance should then be allowed behind the post to the front framework of the seat back, allowing for the upholstery. This dimension on a limousine body is about 19 in. The horizontal distance

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from the lower edge of the steering-wheel rim to a vertical plane tangent to the front of the rear-wheel tires, should be about 48 in. on any closed car. Of course, more room gives more latitude in design. An open car body can be made very satisfactory with 6 in. less.

A rather important consideration in the case of a closed car is the point at which to measure the height. The measurement should be taken where change in design would have the least effect. For instance, if a body were measured in the center and there were a large curve to the roof, one might consider that the measurement would be ample; yet a person sitting in the corner might be cramped for headroom on account of the curving down of the top at the sides. To be safe, it is wise to measure about 8 in. in from the side wall, which would be about the center of the head of the passenger sitting at the outer end of the seat. A body intended for general use by people of all ages requires a reasonably high roof. Elderly people require more headroom when entering a car and do not as a rule like very low seats. A family car generally has the extra seats in fairly frequent use and requires the seats to face forward, necessitating a large body. These seats force a person to sit fairly upright and the roof should be high enough to allow a person of average height to wear a hat and sit in a natural position. A family car is also owned as a means of comfortable transportation, and its appearance should suggest its character.

This immediately brings out the fact that to be truly artistic nothing should look crowded. The design should show that there is a place designed for everything to be carried. A low total height from the ground to the top of the roof is always desirable, but the obtaining of this characteristic is a matter for the chassis engineer. The body itself must be of a certain height irrespective of the chassis and if the chassis hangs high it is impossible to obtain a pleasing effect. The minimum distance from the floor to the roof of a family car should be from 53 to 55 in. The enclosed-drive or sedan type is chosen often by an owner who wishes to drive the car himself. Such an owner is apt to be willing to sacrifice a little headroom in order to give the car a greater suggestion of speed or smartness, so that the headroom can often be cut down 2 or 3 in., but if brought down below 50 in. the car is rather awkward of entrance.

Another important and fundamental dimension is the

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width of the rear seat, and by this is meant the width of the framework of the body on a level with the passenger's shoulders. Most cars require about the same clearance between the rear wheels and the wheelhouse. If the cushion is kept reasonably low, the top of the cushion will be determined by the distance between the inside of the wheelhouses and this will be only about 44 in. If the body has perpendicular sides at this point it can seat only two people, but by cutting in for the wheelhouse more room is allowed for the shoulders, which is really where the greatest space is required. For that reason it is wise to consider the inside width as being that between the framework of the belt rail just below the bottom of the windows. To seat three persons comfortably requires about 54 in., but 2 and sometimes 3 in. can be cut off and still be satisfactory for slight people. Another point that is frequently lost sight of in this respect is the shape of the body. When the body is flat at the side and has round corners the distance between the rear-door pillars, at the belt-rail height, is a very good measurement to use in comparing bodies, but when the body has a square corner it is almost invariably tapered toward the rear; hence this measurement would be misleading as the passengers sit 7 or 8 in. from the rear. The measurement to be exact should be taken close to this spot. These rules have been mainly discovered by experience. It is easier to apply a comfortable body to a modern than to an old-style chassis, on account of the developments in the chassis which is now lower and has a longer wheelbase.

Windshield Evolution

One of the most interesting effects of criticism is the evolution of the windshield. Originally it was perfectly plain and perpendicular without a break of any kind. This gave protection from the wind, but it was found that when wet with rain or snow, the windshield could not be seen through. The windshield was then cut in half, the upper part swinging forward, thus allowing a clear vision in bad weather. But it was still found that the perpendicular windshield reflected objects in the rear, so that at dusk the driver might occasionally be deceived by the reflection of a person already past and apply the brakes suddenly to avoid running over someone. The development then was to slant the windshield,

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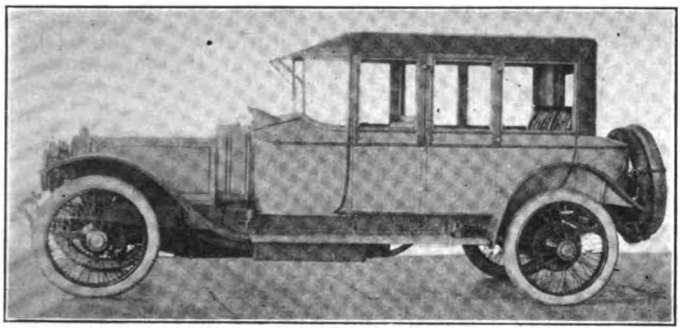
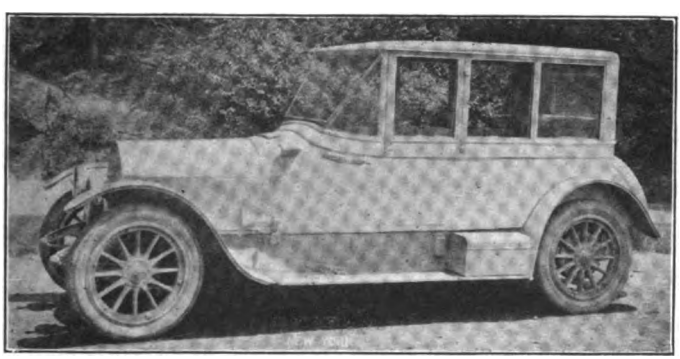


THE 1910 WINDSHIELD IN WHICH THE PILLAR IN FRONT OF THE DOOR IS BROUGHT BACK AND A VERY LIGHT METAL CONSTRUCTION IS USED IN FRONT TO REDUCE THE OBSTRUCTION OF THE DRIVER'S VISION TO A MINIMUM

causing the reflection to drop to the driver's feet. On enclosed cars the development was a little different. Originally, the front frame or pillar interfered very seriously with the driver's vision when he had to turn even a little from a direct straight line, so that accidents often occurred from this cause. To overcome this the front pillar of the body was brought back some 6 or 8 in., to a point on a line with the front of the driver's cushion, and a metal strip only sufficiently wide to hold the glass was brought out in front to keep the required room inside. This windshield was originally made straight and then, with the evolution of the tilted type, it was slanted back to meet the front pillar at the top. This is the general method of making windshields today,



THE 1912 FORM IN WHICH THE WINDSHIELD IS SLANTED TO ELIMINATE REFLECTION

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with the top half folding outward in case of snow or storm. It was found, however, that with the upper half of the windshield out and the top of its bottom half slanting inward to the body, it caught the rain or snow which come into the body when driving in a storm. To overcome this the bottom of the windshield is now slanted in the opposite direction; that is, the bottom is slanted inward a little so that when the upper part is open, the rain or snow strikes this reverse slanted glass and falls on the cowl.

As a commentary upon how ideas regarding what is beautiful or satisfactory in design are modified by an understanding of proper construction, many people at first objected to the slanting windshield solely because of its appearance, but no one will take a straight windshield now, when the matter of looks is considered, because their eyes have become accustomed to the change. Another transition of what appeals to the eye is now in progress with the new windshield last described. Many people objected to this innovation at first but, after studying it and seeing the reason for it, they prefer it to the plain single slant and see beauty in it.

Structural and Artistic Changes

A structural change is often made at the expense of something known to be good. It is then necessary to decide whether the change is more advantageous than what must be sacrificed. This is illustrated when the front pillar is brought back. It is then more difficult to enter the front seat because the corner of the cushion must be cut to allow foot room and a person cannot walk into the seat as when the pillar is the full distance ahead; but it is perfectly easy to get in and out if it is done intelligently. A few seconds of possible slight inconvenience are then sacrificed for hours of probable comfort in driving.

We have now given consideration to the size and relative position of the seats and doors. We have also determined the height of the roof above the floor, that of the floor above the ground being fixed by the chassis. The next step is to design the outside of the body, the wings, etc. Art is simply beautifying the practical. A box with doors and windows built upon a chassis would accomplish a purpose but it would not be artistic; hence it is necessary to determine what parts can be made more delicate and less clumsy. We require less room for

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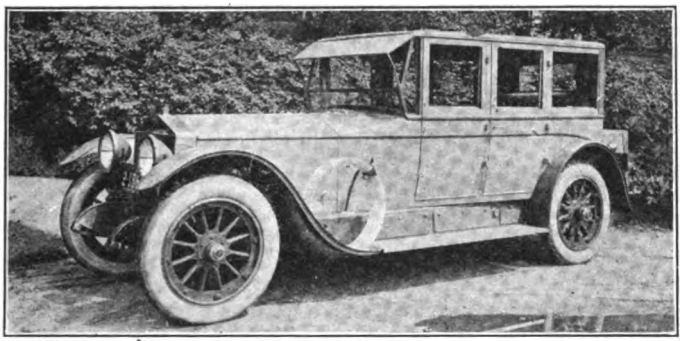

THE LATEST FORM OF WINDSHIELD DEVELOPED IN 1917 IN WHICH THE BOTTOM PORTION IS SLANTED IN THE REVERSE DIRECTION TO REDUCE THE AMOUNT OF RAIN WHICH ENTERS WHEN THE WINDSHIELD IS OPEN

our feet than we do for our shoulders, so the body is invariably made narrower at the bottom than at the top. On a large body the square corners at the rear give way to the round, as that space is not necessary inside the body and round corners tend to make the car look smaller. For the same reason a small car is often made with square corners to give it more character, but the square corner in rear view on a wide car is most ungainly.

The size of the windows is generally a matter of individual taste or fashion and is affected by what is generally termed the belt rail. This is that portion of the body, running horizontally, which marks the division between the lower panels of the body and the upper. If high it gives the appearance of bulk and heaviness. If too low it seems out of proportion because of giving too much glass. A moderately low belt rail tends to make the body look more delicate, and anything in moderation is less apt to go out of style quickly. Most present-day cars have the driver's part enclosed by doors, either low as in an open touring car or fully enclosed. This front part of the car is generally of one surface with the hood and cowl and often continues without a break completely around the body.

Moldings are added to break up large surfaces. They make panels which allow the car to be painted in different colors. A body having no moldings of any kind would have to be painted in one single color as there would be no place to make a change. If it is desired to break a large plain surface, as on a limousine body, a nearly perpendicular molding is generally added in front of the

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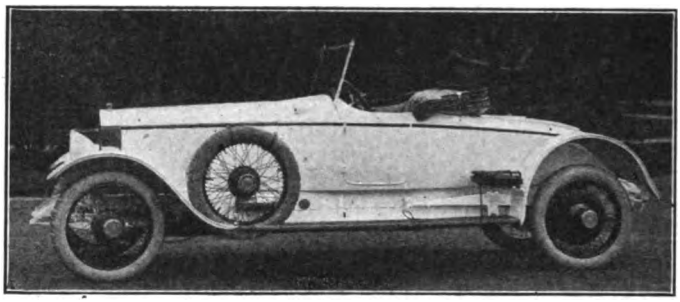

THE ORIGINAL CONCEPTION OF CONTINUING THE SQUARE LINE OF THE BONNET THROUGH TO THE REAR LOWER END OF THE BODY

rear door. This is called the coupe pillar. It divides the owner's part of the car from that of the chauffeur and allows the rear of the car to be painted in a different color from the front. This is perfectly good form for a car which a chauffeur drives, as it differentiates the owner's from the servant's portion of the car. For that reason it is not so advisable on a car that the owner drives, such as a phaeton or enclosed drive type. The molding or pillar referred to is absolutely necessary, for instance where imitation cane work is applied, as otherwise there would be no place to stop it. It is the first molding that is applied vertically. The most important horizontal molding is the belt rail. All moldings tend to shorten or lessen the width of the panel in which they are placed, so that marking the belt rail tends to make the car appear lower to the eye. For that reason two moldings some inches apart, forming what is called a double belt, are employed. This lightens the bottom panel, allowing the belt rail to come lower down, so that the lower panel does not loom so large. This tends to lighten or make the design more delicate. The double belt is practically a continuation of the old crest panels used in carriage days for generations past, on which armorial bearings of the family were placed. These and all other moldings must be placed with great care. They should always be continuous and at least should not end abruptly, as if there were no reason for their existence. The moldings form panels and if the panels are not entirely enclosed trouble in the painting results. One color will then run into another and show at once to the critical eye that the design was not thoroughly worked out. Moldings are often applied to hide the joints of con-

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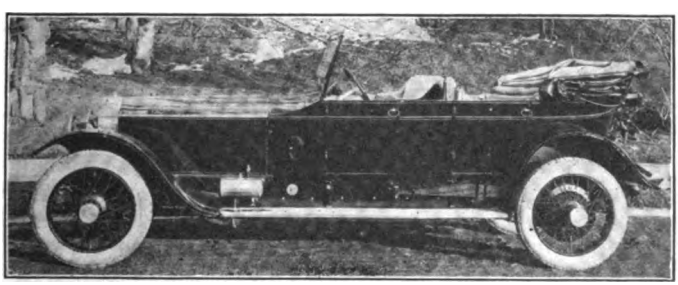
struction, but the same ideas and principles should prevail, that the design must conform with the construction as if done for a purpose and not left to chance; in fact, construction must always be the basis of the design. We construct first and then endeavor to give that construction an artistic effect.

A detail of interior finish or design which is especially adaptable for touring work, where serviceability and cleanliness are important, involves finishing the upper part of the car in its natural construction showing the framework of the body and the bows of the roof. These can easily be varnished or painted to harmonize with the upholstery. Then we have only to stretch the covering for the top over the bows, first putting on a lining which can be painted to match the woodwork. There is practically no wear to this finish, if done well.

Of course, any body cannot be put upon any chassis indiscriminately. A low rakish sort of body requires a correspondingly low slant to the steering post and more space for the driver, for, when we lower the post, it must be made longer as the driver's legs become straighter and need more room. Conversely, a low body cannot be put upon a chassis with a high steering post, as the driver must then sit high to be in a proper position for the wheel. In this position a seat would be out of proportion to the rear of the body. A low steering post with a low body is difficult to use successfully with a family car, as the chassis is rarely long enough to allow the proper entrance to the rear door and this space is shortened by the length required for the driver.

It would seem almost obvious that for the best inter-



ANOTHER EXAMPLE OF THE SQUARE LINE OF THE BONNET BEING CONTINUED AROUND THE UPPER PART OF THE BODY IN A SINGLE CONTINUOUS LINE, THUS MAKING A DOUBLE BELT

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ests of the users of a car it is wise to have as little waste space as possible in the center. It is like the space amidships on a steamer; the center of the chassis is the most comfortable part for riding. Yet open cars are often designed with a second little cowl back of the chauffeur and the space under the cowl is used for cabinets for the storage of small articles, thus giving up the most valuable space in the car for storage. Furthermore, this cowl cuts into the entrance, often requiring a large cut in the bottom of the door, so that it can hardly be called good design. If any storage space is wanted the body can extend a few inches behind the rear seat, making a pocket in the least desirable part of the car.

It is generally good practice to make the car appear as low to the ground as possible and the roof line, of course, bears directly upon this. Keeping the windows as high as the construction of the body will allow tends to make a very light-looking roof and gives the maximum outlook from the interior, but one also sees at once the entire height of the car. If the windows are lowered 2 or 3 in. from the top and the line of the roof rounded over, the car will appear lower although, of course, not as light-looking in this detail. This treatment is therefore perfectly legitimate if this effect is desired.

The position of the extra tires does not materially affect the design, but for touring it is rather impractical to hang them in the rear as that space is needed for the trunk rack to carry luggage. It is therefore wise to carry tires in the wings at each side of the dash. They are also much cleaner to handle if tires have to be changed en route, but for very small light cars, such as runabouts, they must be carried in the rear to give the weight required for traction at the rear of the car.

The design of wings or fenders bears to a certain extent upon the completed design, and here again there has been certain evolution. In early cars the front wings had the outside front end much higher than the inside, instead of being parallel with the ground. This, however, allowed the mud and dirt to be deflected from the wings at such an angle that the wind would drive it into the car; this type was therefore superseded by the present type of wing, which is always kept as close to the wheel as possible. Flanges are also added at the sides of the wings for the same reason, as an additional protection. A slightly rounded wing with flanges gives a delicate light appearance and is desirable with a light-appearing

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body, but there is a large dome-shaped fender without angle of any kind which is eminently practical although not very delicate in appearance. It can be used with good effect on a heavy type of body, but there would be a question whether or not they are in keeping with a delicate design. For a strictly fashionable town car, wings are often made on the type of the old horse-drawn Victoria, that is, a light metal frame covered with leather. This gives a very handsome effect and shows at once that the car is not for touring. It also conveys the idea that the owner is critical and wants his car, like his clothes, for different purposes. Instead of using the almost universal running-board the wings can be made separately with only a step to the rear entrance, and an extra wing brought up from the front of the rear step exactly as in the old Victoria. This naturally does not give the whole car as good protection as does the running-board, but it tends to make the car look shorter and higher and is liked by many as a still further evidence that the car is for town use. However, if used in this way, the wings should be of leather.

While discussing town cars, another detail of the treatment of the chauffeur's part should be mentioned. When leather wings are used, the usual type of fore-doors need not be used. This allows the liveries of the chauffeur and footman to be seen and tends to brighten up the effect, thus differeniating the town from the touring type. For extremely cold weather a light metal frame covered with leather can be used for a temporary door, but as this is only to be temporary for the cold months it should not be a part of the design; this shows that it is exactly as intended, a temporary protection from the weather.

Influence of Weight Upon Design

The question of weight bears only indirectly upon design, as weight is largely determined by the type of construction. As the designers of the chassis use every possible endeavor to save even a few pounds here and there, it should naturally be the duty of the body designer to try to make his part of the car as light as possible, but there is a limit to what can be done here on account of having to consider doors and other parts which require substantial construction in order to work perfectly. Naturally, a door must be set in a frame so firmly that it will not spring and bind the door, making it ineffective.

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Not only must the door frame be rigid, but every part of the door itself must be made stiff enough that it will not rattle. In fact, having everything work smoothly so that it will not rattle, differentiates the car body from the airplane where noises and relative flexibility are matters of small moment. Hence, lessons gained from airplane construction are practically useless to the coach builder.

The glass used in a closed car is probably the heaviest single part. Few laymen appreciate the fact that the ordinary glass used behind the chauffeur weighs about 20 lb., for a thick plate glass has to be used to get one of sufficient clearness. This heavy glass necessitates correspondingly wide runs or grooves in the pillars, which determine the size of the pillars. While the latter might be made lighter so far as strength is concerned, a certain amount of bulk is necessary on account of the glass runs.

There is no construction so light as that employed in the old wooden carriage, and nothing gives as fine a surface when finished, if well made. The white-wood panel used in old coach building was some 10 per cent lighter than the aluminum panel used today so that, all things being equal, a wooden body is about 10 per cent lighter than the corresponding aluminum-covered body. However, aluminum is now used almost entirely for two reasons. It gives more latitude in design. For instance, it is much easier to make large round corners in aluminum than in wood. Also, the paint will stand better against the "working" of an automobile. The twists and turns a car gets over very bad roads or bumpy snow, especially when it is cold, seem to crack any paint on wood panels while the aluminum stands this very much better. Cast aluminum panels are sometimes used, but they are very much heavier.

In conclusion, the highest type of automobile body designing should always be based primarily upon a high degree of practicability.

THE DISCUSSION

H. M. CRANE:—I agree with Mr. Brewster as to the impossibility of a satisfactory closed-body construction on airplane lines. There is no question that, for a given amount of strength, a very flexible construction is undoubtedly the lightest. On the other hand, in my opinion, a body requiring the use of glass, operative doors and similar features, can never be made flexible; that being the case, it must be designed for stiffness. Under such

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conditions, the extreme lightness of the construction used in airplanes cannot be worked out. All engineers engaged in engine design know that most of the disappointment with high-grade steels came from the fact that there were very few places in automobile engines where they could really take advantage of the possibilities of such steels, because a section had to be designed primarily to be stiff, and not necessarily for ultimate strength. This applies even more to bodies, and with the great increase in closed bodies it has been very interesting to see the spread to one company after another of a really proper design of chassis frame.

The chassis frame with 3 or 4-in. side-rails was amply strong to carry any load put upon it, years ago and also today, but is utterly out of the question with a closed body mounted upon it. In fact, the body builder was forced to add 100 to 150 lb. to the body to make it work at all and compensate for the 25 lb. the chassis builder left out.

AUSTIN M. WOLF:—No mention has been made of the necessity of co-relation between the body and the fenders, aprons, windshield, wheels, as in the disk type, and the top of open cars. It is very essential that the design between all these parts be in harmony with the body lines, or their effect and beauty will be nullified. We often find that the curves or straight lines in the side view of a fender, particularly the front, clash with the general line design of the body and hood. In a similar way the use of disk wheels, from an artistic point of view, is dependent upon the balance between the circular surface which they present and the surface presented by the hood, body side and side splasher. These masses usually harmonize best in a low-hung car.

It is becoming gradually apparent that more attention is being paid to the top design of the moderate-priced car than heretofore. The top when up, due to its raised position, presents an accentuated mass and the necessity for harmonious design is extremely important.

Very often a chassis is designed simply from the chassis engineer's point of view, and no thought is given to the body and the mounting of the other units which the word "body" must also broadly convey. It is my opinion that more thought can be given to the original layout, particularly to the frame construction, if we consider the particular body which we wish to use. At the same time, a great deal of weight can be saved by

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suitable frame design in allowing less overhang for the body sills and providing better support for them.

It is unsightly to see a short body mounted on a long frame in which the rear goose-necks, which at their best lack any semblance of beauty, project an undue amount. In this connection we have the advantage of using cross rear springs or the cantilever type, which assist in making a presentable rear end. Too little attention has been paid to this part of the car.

With cantilever springs as used by Rolls-Royce and its many followers, the springs lie outside the sides of the frame. It is impossible to use such a chassis construction with a Cunningham type of body without running-boards, as the springs would be exposed; assuming, of course, that an extremely wide body and sill are not used to bring the body side beyond the outside edge of the spring. Due to such inherent limitations of a particular chassis construction, and the above is but one example, it is evident that the various types of bodies should be considered before the final frame construction, spring mounting, etc., are decided upon.

With reference to the Rolls-Royce type of cantilever spring, it has always appeared peculiar to me that makers using this construction seem to believe that it is an object of beauty. To me it is not, and I believe that a side-splash apron should cover it.

It was surprising to see at the Salon and at the Palace Show how unsightly, from an artistic point of view, a perhaps clever mechanical construction can appear. In designing a chassis we must think of beauty as well as mechanics. A frame was shown without adequate means for covering the unsightly goose-necks at the front end, a cross-tube ran between them and was joined by an exceptionally large hideous casting containing numerous rivets. Mounting the springs on another car outside of the front goose-neck eye, with no attempt to cover this construction, ruined the entire front-end appearance of the car embodying it. Numerous cases were in evidence where a little better quality of sheet-metal work, or more of it, would give a finished appearance to the car.

In addition to the sod-pan apron extending entirely across the bottom of the car, we have side-splash aprons to imitate this effect; the majority of them are a disappointment in that they in no way convey the effect desired. Some are not made deep enough, as was evident on a number of cars, including a foreign car at the

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show; others have been dressed up with bevel edges which do not seem to fit into the design at this point. The regular side-splash apron used with running-boards is sandwiched at its top between the body sill and the frame, and usually presents a horizontal surface which projects a short distance beyond the bottom edge of the body. Most of the side aprons without running-boards have followed this practice, and the flat or horizontal surface thus presented abruptly breaks up the otherwise smooth surface which can be obtained by making the side apron a continuation of the body side surface, curving it inwardly at the bottom.

I believe that a great deal more thought than has been given heretofore should be given to the body, fenders, aprons, etc., and their mounting, from the time the first line for the chassis is put upon the drawing-board.

SPRINGS AND SPRING SUSPENSIONS

By E. Favary[1]

The chief factors affecting the riding quality of a motor vehicle are spring deflection, or amplitude; periodicity, or the number of vibrations per second; and the proportion of the sprung to the unsprung weight. Other factors are the wheelbase, the tread, the height of the center of gravity of the car and the effect of the front springs on the rear ones. The three main factors are considered at some length, various experiments being described and illustrated by diagrams. Spring inertia and the fundamentals of periodicity are then investigated, by experiments and mathematical analyses, in considerable detail. Experiments regarding possible future spring construction are described and discussed and the advantages offered by the suggested suspension are stated as sensitiveness at light loads; a minimum flexure for a maximum of axle motion; sensitiveness at all loads against quick upward thrusts of the axle; reduced weight of the unsprung mass; larger deflections at light loads and proportionately small deflections near the maximum load; and a saving in spring weight.

The chief factors affecting the riding quality of a motor vehicle are: spring deflection, or amplitude;

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periodicity, or the number of vibrations[2] per second; and the proportion of the sprung to the unsprung weight. Other factors influencing riding quality are the wheel-base, the tread, the height of the center of gravity of the car and the effect of the front springs on the rear ones. Speed of travel naturally has an effect upon the spring suspension, and therefore on the riding qualities. I will not here consider the effect of speed or speed variation, but shall bear in mind their relative influence at all speeds, with a wheel of a given diameter and the same quality of tire.

The spring having the largest amplitude of deflection for a given load will flex most, for small or large additional upward thrusts of the axle when the wheel encounters obstructions on the road, with the least perceptible disturbance to the car body. For instance, if one spring deflects 1 in. for each additional load of 150 lb. and another moves the same distance for a 200-lb. load, with deflections not exceeding the elastic limit of the material, the 150-lb. or more flexible spring will produce the lesser intensity of upward shock, even though the time interval during which the upward thrust acts is longer.

Vibrations Per Minute

The periodicity, as well as the amplitude of the deflection, depends upon not only the length, thickness and width of the spring-leaf, considering a single-leaf spring for the present, but also the load that it supports. The

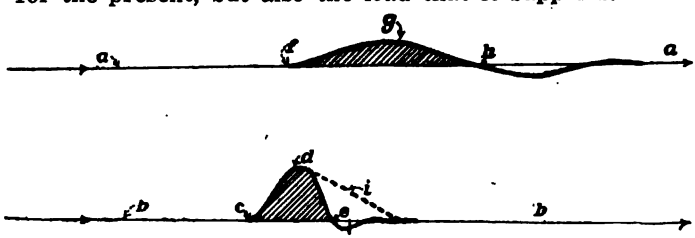

Fig. 1—Path of a Wheel Center in Passing over an Obstacle

greater the static load and the greater the static deflection of the spring, or the position of rest when the load is applied, the slower the vibrations per minute. Increase the static load and the deflection will increase the fiber

[2] The term "vibrations" is used instead of "oscillations", since the best writers in physics use "oscillation" to mean one-half of a complete vibration; thus, a vibration means two oscillations, one up and one down.

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stress in the spring; so that we can state that the greater the fiber stress the slower the periodicity.

It is not so much the height through which the body is raised as the rate of speed at which it is raised that affects the passenger's comfort, although both are of great importance. The final requirement of a good spring suspension is that it impart to the car body the least

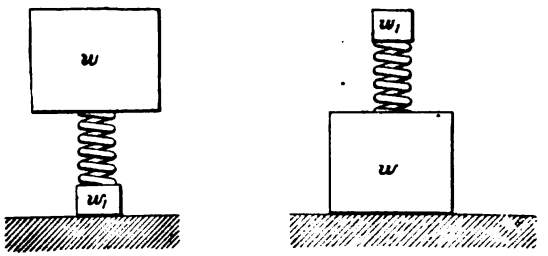

FIG. 2—KEEPING THE PROPORTION OF SPRUNG TO UNSPRUNG WEIGHT LARGE IS IMPORTANT

amount of upward motion and at the slowest speed. Tests[3] have disclosed the fact that the axle, when the wheel travels over an obstruction, causes the wheel to jump over the obstacle in each case and come to the ground beyond it (See Fig. 1); and it appears that the shape of the obstacle makes no appreciable difference, unless its slope is very gentle. It has also been shown that the wheel reaches the top of its upward motion almost before the car body begins to move upward, and that when the wheel has completed its "jump" and returned to the ground the body has traveled only 40 per cent of its upward path.

In Fig. 1 the lower line denotes the path which the center of the wheel describes when surmounting the obstruction, while the upper curve shows the path pursued by a point of the frame or body just above the center of the wheel. Tests have also shown that when a stiffer spring is used the oscillations of axle and body cease sooner, but that the acceleration of the upward motion of the body is greater, which means more discomfort.

RELATION OF SPRUNG TO UNSPRUNG WEIGHT

Fig. 2 illustrates graphically the importance of keeping the proportion of sprung to unsprung weight very great. A comparatively heavy weight is represented by w, while

[3] *Proceedings* of the Institution of Automobile Engineers, vol. 7, p. 451.

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w_1 is a small weight. In the first instance a small weight at the bottom, corresponding here to the axle and the wheel, will have relatively little effect upon the greater weight above, since the latter is so much heavier; the greater weight will be influenced relatively little by what the lighter weight may do. In the second case we have a heavy weight at the bottom, which, if it begins to move upward, will continue to do so, irrespective of the small weight above, and no matter how weak or strong the spring above may be, it will carry the small weight along with it. Therefore, as far as riding quality is concerned, a lighter unsprung weight will be superior, since it has the least effect upon the sprung weight.

Let us consider the following example, on each rear wheel:

Weight of car, lb.	4,000
Weight on each rear wheel, lb.	1,200
Unsprung weight for each rear wheel lb.	300
Sprung weight for each rear wheel, lb.	900
Horizontal speed of car, ft. per sec.	72
Approximate speed of car, m.p.h.	49

In considering the action of a wheel of a moving car when striking an obstruction over which it rises, so many modifying factors are involved that it is doubtful whether, with the data available at present, a correct and complete mathematical analysis is possible. Still, certain assumptions can be made that more or less approximate true conditions, and a result secured such as will give some idea of the magnitude of the forces involved. When the wheel, moving along a horizontal surface, strikes an obstruction, there is a tendency to reduce the speed of the car because there is imparted to the wheel of the car potential energy that has been acquired at the expense of the kinetic energy of the car. Since the mass of the car is large compared with the unsprung weight per wheel, we can assume as a first approximation, that the car speed remains unchanged while passing over the obstruction. The simplest assumption possible is that the path of the hub of the wheel is a straight line inclined at a definite angle to the horizontal. This is equivalent to assuming that the wheel is traveling up an inclined plane.

When the wheel strikes an inclined plane there is a tendency to retard its motion, since it cannot acquire upward velocity in zero time. This brings about a changed deformation of the tire and a slight distortion in the

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supports dragging the axle and the wheel for an instant has a velocity which is slightly less than that of the car. As the distortion in the dragging supports disappears, due to the resiliency of the material, the wheel again catches up in speed and finally when the distortion has completely disappeared the speed of the car and of the wheel is identical and the latter has attained its maximum vertical velocity. From the foregoing it follows that the vertical acceleration is variable.

Let us further assume that the wheel in passing over an obstruction rises through a vertical distance of 1 in., and that in doing so it travels a horizontal distance of 4 in. (See Fig. 3), and that at this instant the wheel

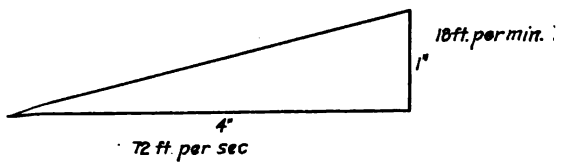

FIG. 3—VERTICAL AND HORIZONTAL VELOCITIES OF A WHEEL IN PASSING OVER AN OBSTRUCTION

has attained its full vertical speed. The wheel must then have a vertical velocity of 18 ft. per sec. Since this vertical velocity was acquired while the wheel traveled a horizontal distance of 4 in. or 1/3 ft., the time interval is 1/216 sec. Then the average acceleration is:

$$a = \frac{v}{t} = \frac{18}{1/216} = 3888 \text{ ft. per sec. per sec.}$$

Because the acceleration varies from zero to zero, the actual acceleration for some points of the path must be considerably greater than the value found for the average. Ordinarily the axle will not rise 1 in. in traveling 4 in. horizontally, but this rather unusual case was purposely selected to indicate roughly the magnitude of accelerations that do occur. The upward acceleration of the axle amounting to anywhere near the above figure, will exert a tremendous force against the body and tend to give it a definite upward acceleration and velocity. This upward force of the axle can be reduced by decreasing the unsprung weight and also by some means that permit the axle to move slightly backward with respect to the frame, when subjected to an upward thrust. This is often accomplished in practice by raising the front end of the spring, for instance.

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One function of the spring is to decrease the upward velocity and acceleration of the sprung weight, or car body, and to increase the distance of its horizontal travel while in a raised position. The spring thus transforms the vertical distance of the body deflection, either up or down, into a horizontal distance, whenever the wheel surmounts an obstacle or sinks into a rut. In Fig. 1, if the wheel hits the obstruction at *c* it will quickly rise to *d*, that is to say, in a very short horizontal distance, and will soon thereafter drop back to its normal path *b b*. The body above will start to rise at *f*, reach its highest peak at *g* and then slowly descend to the normal path, *aa*. It is evident that the later the curve of the body-path begins to rise, after the wheel starts its upward acceleration, the lower the peak *g*, or the longer the time required for it to reach its maximum height. The greater the horizontal distance *f h* the better will be the riding quality of the car. If no kinetic energy is absorbed by the spring the area of the shaded section under the lower curve will be approximately equal to that under the upper curve, but the greater the amplitude of the spring deflection and the lower its periodicity, the lower and longer will be the upper curve, described by the body, and the higher and longer the lower curve described by the wheel center. A flexible spring, one with a large amplitude, will permit the axle to fly up very rapidly and to a great vertical height; while a low periodicity will return it to the normal path more slowly, as shown by dotted line *di* (Fig. 1). Even if the upper curve were higher, if it is proportionately longer before returning to normal, a more favorable riding quality will result.

While the formula for finding the periodicity of a spring, or number of vibrations per minute, can be found in any textbook on the subject, let us analyze it by simple practical experiments. If we take four leaves of spring steel, all of which are identical as to length and thickness, and if we hold one end fixed and leave the other free to vibrate, we find that without any load the periodicity will be the same whether we have one leaf or two, three or four leaves together. If the leaves are straight and smooth, so that there is no friction between them, we will also find that the amplitude of deflection is practically the same for the same load per spring, as is also the number of vibrations, before the spring finally stops. If we now place a weight of 1 lb. on the free end (See Fig. 4), we find the amplitude

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of deflection larger but its periodicity lower. For instance, in one case, without any load on the free end, a certain spring 30 in. long had a periodicity of 126 vibrations per min. regardless of the number of leaves. When 1 lb. was placed on the free end, the vibrations were reduced to 100; with 2 lb. to 86; with 3 lb. to 78; with 4 lb. to 73, etc. When 1 lb. was placed on the spring composed of two leaves, the periodicity was 112, but with 2 lb. it was 100; with three leaves, 1 lb. reduced the vibrations to only 116; 2 lb. to 108; 3 lb. to 100, etc. This is shown graphically in Fig. 4. With 1 lb. on one leaf, 2 lb. on two leaves, etc., the periodicity as well as the amplitude remains the same[4] By shortening the leaf to 24 in. the vibrations were increased to 196, without load, while with a 1-lb. load they dropped to 142; with 2 lb. to 120, and with 3 lb. to 110. Two leaves shortened to 24 in. gave a periodicity of 172,

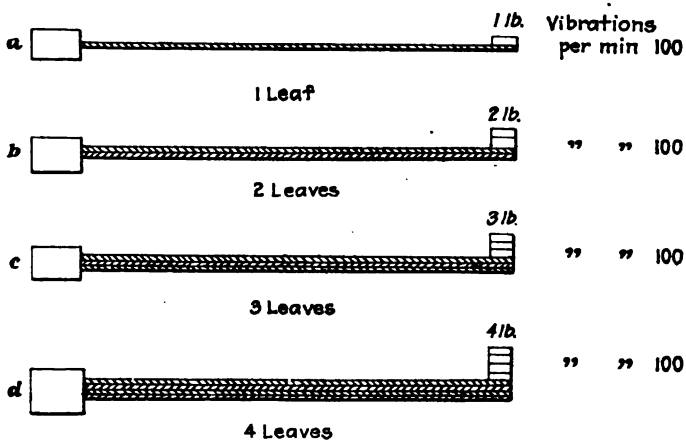

FIG. 4—THE PERIOD OF AN UNLOADED SPRING IS THE SAME IRRESPECTIVE OF THE NUMBER OF LEAVES

with a 1-lb. load; 142 with 2 lb., etc. Three leaves gave a periodicity of 176 with a 1-lb. load; 142 with 3 lb., etc. We can state, therefore, that, everything else being equal, a heavier load, which is always accompanied by a larger static deflection, causes a greater fiber stress in the spring; and the heavier the load, or the greater the deflection or the greater the fiber stress, the slower the periodicity.

[4] It might be mentioned that these tests were not carried out with extreme accuracy; also, the load was not pound weights, but blocks of uniform size and small weight.

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Let us now consider the effect of friction between the leaves. In the simple experiments covered by *d*, Fig. 4, rubber bands were tied around the springs to create friction between the leaves. We still obtain vibrations at the rate of practically 100 per min., but instead of being able to count the vibrations for a whole minute, they are damped out in about 10 sec. and the static deflection is less than it was without the rubber bands. It is thus evident that friction between the leaves reduces the amplitude of deflection and the number of spring-inertia vibrations before the spring comes to rest.

Spring Inertia

Another simple experiment showed that a thin spring, such as is shown in Fig. 5, when hit quickly on the free end, first assumes the shape *a*, then *b*, and finally *c;* when it will continue its vibrations as in *c*, gradually declining in amplitude until it comes to rest. In other words, when quickly applying the load at the free end, the spring will not at first be flexed over its entire length but gradually flex from the point where the load is applied toward the fixed end.

If the spring is very thin, air resistance may be the chief cause of this retarded deflection of a portion of the spring, but inertia is an important factor. We may ask whether something else does not prevent instantaneous flexure of the entire length. It seems that scientists are agreed that no delay is caused by molecular intercommunication in the spring material itself. On the other hand, Thomson and Joule discovered that metal, when subjected to stress within its elastic limit, experiences a very small change in temperature, diminution for tension stresses and an increase for compression stresses, and that the change in temperature is proportional to the change in the stress applied. I believe it was Lord Kelvin who found a difference in the electrical resistance of stressed and of unstressed metal. It would be interesting to hear from members who have conducted experiments, whether to their knowledge springs were ever set vibrating in the laboratory at such a rate as to attain an acceleration of 3000 or 4000 ft. per sec. per sec. at their free ends. The fact that a spring does not respond instantaneously over its entire length, as disclosed from the experiment mentioned before (See Fig. 5), would indicate that if we set the

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FIG. 5—POSITIONS ASSUMED BY A THIN SPRING AFTER BEING DEFLECTED

spring vibrating at a slower rate it would be more satisfactory.

FUNDAMENTALS OF PERIODICITY

We may briefly analyze the fundamental equation governing the time t in seconds, required for one period or one oscillation down and one up. Assume a helical spring suspended vertically and supporting a mass m whose weight is mg lb.; then the mass will come to a position of equilibrium when the restoring force of the spring is equal to mg. According to Hooke's law, if f is the force in pounds required to elongate the spring one unit, then fs will be the force required to elongate the spring s units. Since the spring obeys Hooke's law, the restoring force tending to bring the mass to its position of equilibrium is proportional to the displacement from the position of equilibrium, and, therefore, if free to vibrate will execute a simple harmonic motion.

The acceleration for a simple harmonic motion is $\frac{4\pi^2}{t^2} s$.

Therefore, the force for the displacement s is $m \frac{4\pi^2}{t^2} s$,

but this must be equal to the restoring force. Therefore

$$m \frac{4\pi^2}{t^2} s = fs, \text{ from which } t^2 = \frac{m4\pi^2}{f} \text{ and } t = 2\pi \sqrt{\frac{m}{f}}$$

The mass and the restoring force alone govern the periodicity. The restoring force in a leaf spring depends on the length, thickness and width of the leaf and on the modulus of elasticity.

In comparing leaf and coil springs proper allowance must be made for the spring mass involved, but in general the formula governing all vibrating bodies is:

$$t = 2\pi \sqrt{\frac{\text{Resistance}}{\text{Restoring force.}}}$$

In this connection, it will be interesting to compare

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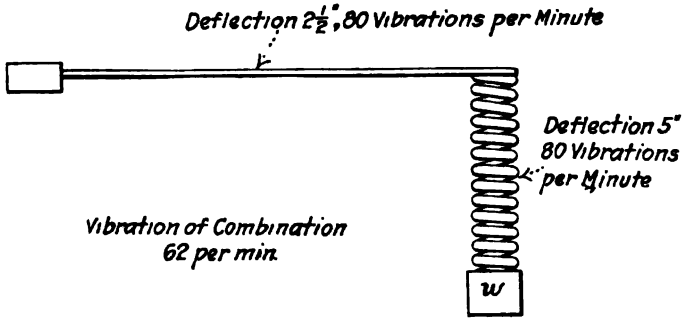

FIG. 6—COMBINING A LEAF AND A COIL SPRING REDUCES THE PERIODICITY OF EACH

the periodicity of a leaf spring having a certain deflection with that of a coil spring with the same deflection. Suppose a single-leaf spring, like those shown in Fig. 4, be given by the application of a certain weight a deflection at the end of the spring of 2.5 in.; and suppose that upon setting it vibrating its periodicity is found to be 80 vibrations per min. By taking a helical spring of such length and stiffness that the same weight deflects or elongates it also 2.5 in., we obtained by actual test a periodicity of 120. Of course, this amount would vary somewhat in changing the weight of the spring, but it can be stated that ordinary coil springs used in practice, for supporting and cushioning similar loads, have a very much larger number of vibrations per minute than leaf springs carrying the same load. To reduce the number of vibrations to that of the leaf spring, 80 per min., it was necessary to increase the length of the coil spring to such an extent that its static deflection for the same weight amounted to about 5 in., or double the deflection of the leaf spring.

If the two springs, having the same periodicity, are now taken and connected together in series as shown in Fig. 6, and the same weight be suspended therefrom, we obtain a combined periodicity[5] of 62. It is thus seen that a combination of two springs reduces the periodicity. It has been stated by some engineers that the use of coil springs at the ends of the leaf spring, such as are employed in certain coil-spring "shock absorbers," does not reduce the periodicity of the combination. I have found in every case that such application brings

[5] The experiments were crude, hence an error of 2 or 3 per cent is likely.

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about a diminution in the number of vibrations per minute, although in some cases, when the proportion of coil-spring deflection to leaf deflection is very small, as with the coil-spring "shock absorbers," the decrease is almost negligible. It has been found that by attaching a coil spring at the end of a leaf spring, especially when the coil-spring deflection or elongation per unit weight is considerably greater than that of the leaf spring, the coil spring does reduce the acceleration of the free end of the leaf spring. When several leaves are used and considerable frictional surface between the leaves is thus introduced, the coil spring will absorb slight vibrations without transmitting them perceptibly to the leaf spring.

This is precisely what happens in practice by the application of coil springs to the ends of leaf springs. They absorb the small rapid vibrations, while the leaf spring is practically at rest, but in the case of large vibrations, the leaf-spring deflection is the governing factor. Nevertheless, the deflection of the coil spring is added to that of the leaf spring, and reduces the acceleration of the "free" end of the leaf spring or that end to which the coil spring is attached. It is believed that better results could be obtained with supplementary springs attached somewhere between the leaf spring and the axle, for in that case the small vibrations would not of necessity be transmitted through the entire length of the leaves before reaching the coil spring; and in addition, this would add to the sprung weight as far as its effect on the coil spring is concerned, since the latter would then carry the weight of the leaf spring.

Having found that the ordinary coil spring of a given deflection has a higher periodicity than a leaf spring, it appears that by substituting a separate leaf spring between the main spring and the axle, better results might be expected. My experience in this connection may be of interest. While engaged recently in rede-

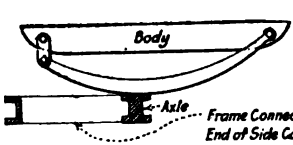

FIG. 7

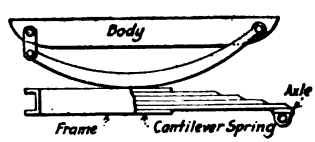

FIG. 8

TWO EXAMPLES OF SIDE-CAR SPRING CONSTRUCTION

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signing a rather heavy motorcycle with a side-car which, among other defects, rode most uncomfortably, I found that the side-car frame was rigidly attached to the axle (See Fig. 7). There were leaf springs 38 in. long between the frame and the side-car body, but the proportion of unsprung to sprung weight was comparatively large, because the frame rested directly on the axle. There was available also an experimental side-car frame terminating in a short, stiff quarter-cantilever spring attached to the axle. The body was mounted directly on the frame. In testing this on the road it was found to be as bad as an empty truck as far as riding quality is concerned. The body was consequently removed and the first side-car body with semi-elliptic springs placed on the frame, which terminated in the cantilever spring, as shown in Fig. 8. This gave a combination of short flat springs between the axle and the frame with the ordinary semi-elliptic springs underneath the body. The first test of this combination was a revelation. It was the unanimous opinion of those who tried it that it rode with greater comfort than any high-priced automobile. This shows the advantage of having an extra spring below the main one. In the first place, this gives an added deflection, although in this case the deflection per unit weight was very small indeed compared with the main spring, and this reduced the periodicity of the body, and secondly the acceleration and velocity of the free ends of the main spring were therefore less.

Thus, to obtain increased comfort, one suggested method is to provide an auxiliary spring, preferably of the leaf type. Another great advantage of the leaf spring is that the inter-leaf friction reduces the vibrations to a very small number before the body comes to rest, while with coil springs the vibrations continue for a long time, and this is to be avoided in car suspension. On the other hand, excessive friction between the leaves interferes considerably with spring deflection and renders the spring much stiffer, thus imparting greater shocks to the sprung weight. It seems that comparatively little friction between the leaves, as for instance when they are lubricated, is sufficient to reduce the total number of vibrations before coming to rest to that required for comfort, except when going at high speed over bad roads, in which case added friction is advantageous. Friction in the spring shackles also influences the deflection; likewise the angle of the shackle with respect to the spring. If this angle is such that the

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stress applied to the spring is at right angles to the leaves, it will impart purely flexure stresses to them. If at a greater angle, it will cause, in addition, buckling stresses; and if the angle is smaller, tensile stresses.

Another point worthy of notice is that, with leaf springs composed of a number of leaves, a certain load is required before the spring begins to deflect, due to the inter-leaf friction. This is a serious drawback in both automobile and truck applications; in the first case it renders a touring car less comfortable unless fully loaded, and in a truck it means excessive jars and shocks when empty or only partially loaded. The latter, under such conditions, might as well have no springs, in many cases, since at such loads there is very little, if any, spring deflection. The result is rapid deterioration.

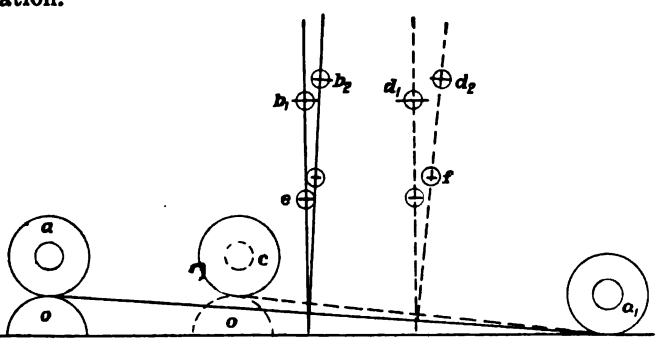

FIG. 9—EFFECT OF THE HEIGHT OF THE CENTER OF GRAVITY AND THE LENGTH OF THE WHEELBASE

The effect of the height of the center of gravity and of the length of wheelbase is illustrated in Fig. 9. Consider first a and a_1, which represent respectively the front and rear wheel of a car having a long wheelbase. Let b_1 represent a point in the body of the car. When the front wheel surmounts an obstruction o, point b_1 will be moved to b_2, due to the angular rise of the front wheel with respect to the normal position of the rear wheel. In this case the backward distance is very small compared with that shown in d_1 and d_2, which represents an analogous case with a short-wheelbase car. It is the backward or transverse motion that causes the passenger discomfort, rather than the vertical motion, everything else being equal, and naturally the greater the horizontal distance through which the passenger is moved, the greater the discomfort. These remarks apply

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also to the width of tread, as affecting side-to-side motion. The illustration moreover discloses what would happen if the points b_1 and d_1 were lowered, or the center of gravity of a car were lowered; the horizontal or transverse motion is reduced when the car wheels rise over an obstruction or sink into a rut.

Possible Future Constructions

Having so far considered the inherent qualities of the present ordinary types of suspension and seen how the addition of auxiliary springs will improve the suspension, we will now consider possible future constructions where no auxiliary springs are required, keeping in mind that springs are not sensitive at light loads, do not respond instantaneously under very rapid application of load or less energy is required to deflect a spring mass at a slower rate of speed and that a relatively great length of spring is necessary to obtain a large deflection and low periodicity. The spring deflection increases uniformly with the load; hence, to obtain more comfort, a greater total deflection must be provided. This is objectionable for several reasons, such as added cost and weight and increased inertia.

Let us first consider the effect of a lever arrangement, such as to permit a large movement of the axle compared to the frame and result in small spring deflection (See Fig. 10), to ascertain whether this holds any promise for spring suspensions of the future. Here *a* represents the axle, *b* a lever or solid beam pivoted to *e*, *c* a bracket supporting the lever and attached at its upper end to the frame *f*, and *d* a spring of any description. By moving the axis *e* farther away from the axle, the spring flexure can be made very small, if desired, for a large upward motion of the axle. But the one great disadvantage of such a system is the inertia of the beam *b*. A sudden blow of a certain rapidity and intensity will break the beam at its pivotal point, scarcely flexing the spring. For motor vehicles, therefore, where the upward acceleration of the axle is high, it is believed such a construction is impractical and needs no further comment. However, if the beam *b* were an ordinary cantilever spring with its end pressing against another spring *d*, which, if desired may be a coil spring, very much better results could be obtained.

Next, consider a semi-elliptic spring *a*, attached to the frame (See Fig. 11), with suspension members *c* connecting the spring-eyes to the axle *d*. This system

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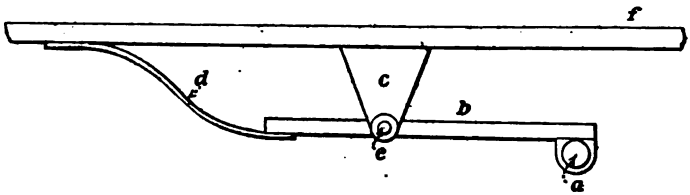

FIG. 10—A LEVER ARRANGEMENT WHICH PERMITS A LARGE MOVEMENT OF THE AXLE RELATIVE TO THE FRAME AND A SMALL SPRING DEFLECTION

offers at first sight the advantage of being very sensitive at light loads, when the axle is only slightly higher than the spring-eyes. In this case, when the axle is moved upward to *e*, the spring-eyes will move from *h* to *i*; this is a smaller distance than the axle travels and the greater the distance between the spring-eyes the smaller the travel of the latter for a given distance of axle movement, based on the principle of the catenary. Turnbuckles *t* can be provided to tension the spring in the amount required for a satisfactory static deflection. The disadvantage of this construction is that the pull or tension exerted on the spring leaves is not conducive to purely flexure stresses, since the greater the spring flexure or the upward movement of *e* the greater the buckling stress, because the force tending to flex the spring has its seat at the axle. The spring will therefore flex in the reverse direction from that of the usual semi-elliptic type, and I understand that for this reason spring-makers are averse to springs of this kind. By looking at this drawing it will be understood that if the axle moved still higher than shown, it would soon reach a point where the tendency is to flex the spring backward, and this would render such a construction impractical. A different arrangement which in my opinion offers a field for future development is that disclosed in Fig. 12. Suppose we take springs similar to

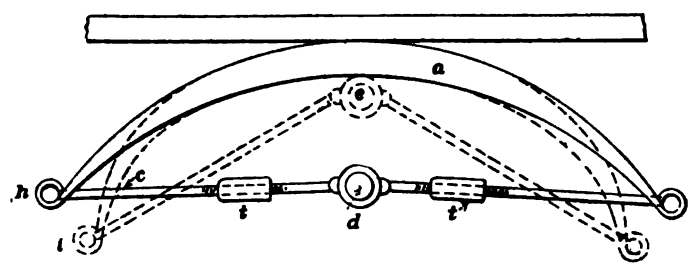

FIG. 11—A SEMI-ELLIPTIC SPRING ATTACHED TO THE FRAME

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those used in the former experiments and shown in Fig. 4, and attach them rigidly to the frame in a vertical or nearly vertical position, and then connect the free ends of such springs by a cable *a*, or two rods pivoted in the center. If we now apply a load *w* at the center of the cable, we shall obtain a certain deflection depending upon the magnitude of the load, the span between the spring ends *bb* and the tension in the springs *ss*. Suppose we

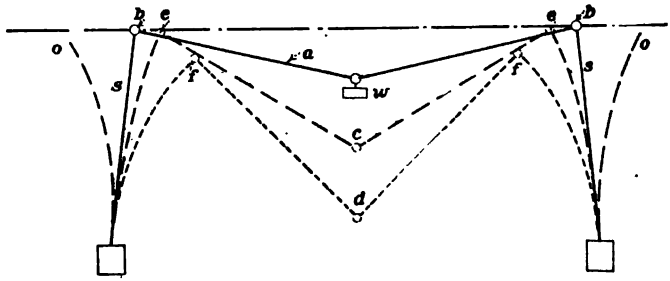

FIG. 12—A SPRING ARRANGEMENT OFFERING POSSIBILITIES FOR FUTURE DEVELOPMENT

now increase the load so that the center of the cable will be deflected to *c*; the spring ends will move inward from *bb* to *ee*, a distance small in comparison with the amount *w* has moved. Thus, for a large deflection in the center we have a small spring flexure. If now the load is still further increased, the weight will reach *d*, while spring ends *e* will move to *f*. It is noteworthy that while the distances *w* to *c*, and *c* to *d*, are equal, the spring deflection is about double in the second instance. In a rough test under these conditions the deflections under various loads and their periodicity were measured, the distance between the center of cable and spring-eyes being 2 ft. The spring tension was adjusted so that the same weights as were used in

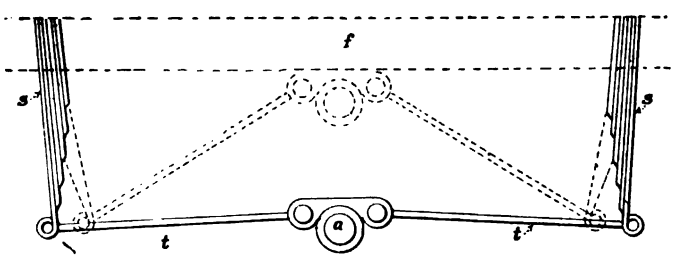

FIG. 13—AN ARRANGEMENT IN WHICH THE SPRING DEFLECTION IS ONE-THIRD THAT OF THE LOAD

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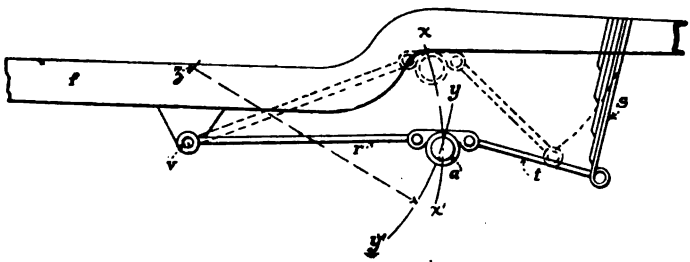

FIG 14—REPLACING ONE SPRING AND ONE TENSION BAR BY RADIUS-RODS

previous experiments (See Fig. 4) gave deflections measured vertically at the center of the suspension where the load was applied and periodicities as given in the accompanying table:

Number of Weights	Deflections, in.	Vibrations per min.
1	3.50	96
2	5.75	82
3	7.50	76
4	9.00	73
5	10.10	70
6	10.80	69

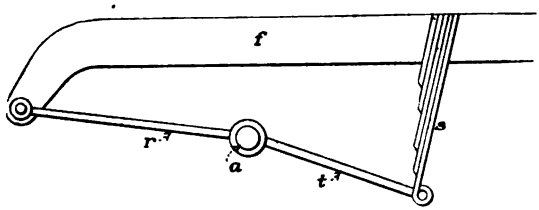

FIG. 15—A FRONT-SPRING ARRANGEMENT EMPLOYING RADIUS-RODS

When the distance between the spring-eyes and the point of load application was increased to 30 in., the periodicity was found to be a trifle lower when the tension was adjusted so that the application of the same load gave a similar load-deflection. With a greater distance, a greater spring-tension was necessary for the same load-deflection. However, with the same spring-tension maintained, the deflection under a given load will be greater.

Fig. 13 shows one way in which a type of suspension can be applied to a motor vehicle. In this case *f* is the frame, *ss* the springs, *a* the axle, and *tt* the tension

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bars. In this example the springs, as seen, deflect only about one-third the distance of the load deflection. The construction illustrated can be simplified by using radius-rods, commonly installed on motor vehicles, to take the place of one spring and one tension bar, as shown in Fig. 14. Fig. 15 shows a similar arrangement for the front spring; f is the frame, s the spring, t the tension rod, r the radius-rod and a the axle. In Fig. 14 the arc xx_1 shows the path of the axle travel when the spring is flexed. To make the axle go backward as well as upward when meeting an obstacle, the anchorage of the radius-rod can be moved higher, to z, for instance, in which case the axle will travel along the arc yy_1. In addition to overcoming the defects of the ordinary spring suspensions before mentioned, with this type of suspension the weight of the spring is removed from the axle and added to the sprung weight, which we have seen before is conducive to added comfort.

Let us now examine the tension in the rods and the bending moment of the spring at the spring seat. We will assume that the pull exerted is at right angles to the spring leaf, as it can be in practice with this type of construction (See Fig. 13). Suppose the weight w at normal load is 1000 lb. and at maximum deflection 2000 lb.; the length l of the tension rods, that is to say, the length between the axle and the spring-eyes, is 24 in. If the maximum deflection is 10 in. from the horizontal position (See Fig. 16), the tension t in the rods pulling against the springs can be found by direct proportion:

$$\frac{l}{t} = \frac{2d}{w} \text{ or } t = \frac{lw}{2d} = \frac{24 \times 2000}{2 \times 10} = 2353 \text{ lb.}$$

If the free length of the spring, from the spring-eye to the seat, is 14 in., or approximately 1.17 ft., the bending moment at the spring seat will be 2353 x 1.17 = 2750 ft.-lb. approximately. This would compare with a semi-elliptic spring somewhat as follows: Length of spring approximately 56 in., with a free length on each side of 26 in. Spring deflection 1 in. for every 200 lb. of load. Normal 1000-lb. load deflection 5 in. and maximum total deflection 10 in. at 2000 lb. We have at the maximum deflection 1000 lb. at each side of a spring length of 26 in., or 2.17 ft., and the bending moment is 1000 x 2.17 = 2170 ft.-lb., about one-quarter less than

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with the above suspension. In spite of that, the weight of the two springs of Fig. 13 can be made less, since their combined length is not much more than one-half that of the semi-elliptic. The weight of the constructions shown in Figs. 14 and 15 is approximately one-half that of the suspension of Fig. 13.

With these types of suspension provision must be made for the lateral strength of the frame, but there

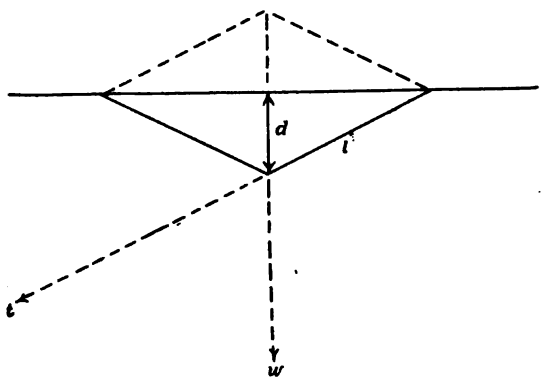

FIG. 16—DIAGRAM SHOWING THE RELATION BETWEEN WEIGHT, DEFLECTION AND LENGTH OF THE TENSION ROD

are various simple means available for accomplishing this. One feature which I felt uncertain about without a practical model was the amount of rebound as compared with the ordinary semi-elliptic spring. I accordingly applied this suspension to the rear of a Ford car and was surprised at the absence of large rebounds. Evidently the friction between the leaves was sufficient to dampen the oscillations very quickly.

To summarize, the advantages that the suggested suspension appears to offer are: Sensitiveness at light loads; a minimum flexure for a maximum of axle motion; sensitiveness at all loads against quick upward thrusts of the axle; reduced weight of the unsprung mass; the spring deflection does not increase uniformly with the load but provides larger deflections at light loads and proportionately small deflections near the maximum load, and a saving in spring weight. The practical development of this type of suspension will no doubt disclose a number of minor problems, but none of these is in my opinion impossible of solution. The type appears to me

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to be one most promising as yielding improvements over existing suspensions.

THE DISCUSSION

DR. BENJAMIN LIEBOWITZ:—The diagrams (Fig. 2) in Mr. Favary's paper showing the desirability of low unsprung weight are somewhat misleading, in that he has assumed the same spring for both large and small sprung weights. For a basis of comparison, however, the same static deflection should have been assumed. This fact makes the problem more complicated, but quantitative results were worked out and curves drawn (See Figs. 11, 12, 13, 14 and 18) in a paper I read before the Society in 1916 entitled On the Dynamics of Vehicle Suspension.[6]

The advantages of a low unsprung weight lie not only in the reduced vertical motions of the axle and body, but even more in the reduced fore-and-aft shocks and the increased ability of the car to hold the road.

Mr. Favary illustrates his theories with accelerations of 3888 ft. per sec. per sec. This is about 120 times the acceleration of gravity. Now, from the laws of motion we know that to impart to a body an acceleration of 120 times gravity, we must impress upon that body a force equal to 120 times its weight. The unsprung weight assumed in the paper is 300 lb. Hence, the wheel would have to have impressed on it a force of $120 \times 300 = 36{,}000$ lb. Since the wheel load for which the axle was designed is 1200 lb., a factor of safety of 30 would be required in the wheel, bearings, axle, etc. Obviously, such accelerations do not occur, except in serious accidents, and have no effect on spring design. In arriving at this acceleration, the author speaks of upward wheel velocities of 18 ft. per sec. To give some idea of what happens with upward velocities of only 12 ft. per sec., reference may be made to the curves of Fig. 14 of my above cited paper.

The experiments described in Mr. Favary's paper cannot be applied to vehicle suspensions, because masses were attached to the spring whose weights were of the same order of magnitude as the spring itself, whereas, in all practical applications, the weight *on* the spring is fifteen to thirty times the weight *of* the spring. The periods, and there are many of them, of a spring itself are of little importance; it is the period of the assembly, spring

[6]S. A. E. TRANSACTIONS, vol. 11, part 1, p. 186.

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and sprung mass, that counts. To illustrate by a very rough analogy, imagine an anchor-ring hung by a string so as to form a simple pendulum; the anchor-ring will have certain periods, which can be excited by striking it with a mallet; but these periods have nothing to do with the period of the pendulum, as a whole.

Spring inertia is a complicated subject. Those who may be interested are referred to vol. I of the Theory of Sound, by the late Lord Rayleigh. The complication lies in the fact that the velocity of propagation of transverse waves in a bar or plate is not a constant, as in the case of longitudinal vibrations, but increases with the frequency of the vibrations. I went into the theoretical side of this matter to some extent a few years ago and found that the inertia of the spring enters very little into the practical aspects of the problem. This conclusion has been experimentally corroborated several times; I may cite, for example, the steam-hammer test which I made several years ago on a full-sized 2-ton truck spring, which was subjected to conditions far more drastic than would ever be encountered under the most severe service conditions. I do not know how high the accelerations due to the blows were, but they were certainly far higher than encountered in actual practice. If spring inertia would enter at all, it would certainly enter here, but there were no indications that it played any appreciable rôle. I shall revert to this test presently.

In the absence of more information on the experiments described, I cannot make any further remarks on this point, except to say that a bar can be made to vibrate transversely in a variety of modes; but this is no indication that the bar, when placed in a leaf spring, will vibrate in partial modes under actual service conditions.

The result of the experiments mentioned in Mr. Favary's paper, that to obtain a given period with a mass hung by a coil spring, twice the static deflection is necessary as compared with a leaf spring, is astonishing; and all the more so, since the author first derives the period formula,

$$\text{Period} = 2\pi\sqrt{\frac{m}{k}}$$

which is readily transformed into

$$\text{Period} = 2\pi\sqrt{\frac{\delta}{g}}$$

where δ, the static deflection, enters as the only variable.

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Here again the author probably used weights which were smaller than the weight of the coil spring itself.

If there is any doubt as to the accuracy of the period formula, as applied to a coil spring whose mass is small compared with that of the suspended weight, which condition always obtains in practice, it can be checked on the seismograph which I have here. It is true that a coil spring can be more easily set into partial modes of vibration than a leaf spring; but if this made much practical difference, we should feel on the finest Pullman cars a constant disagreeable tremor, due to the impact forces of steel wheels on steel rails; which forces are much higher than those encountered in motor vehicles.

There is one other point in this connection. Assuming that a given coil spring, by itself, has higher natural frequencies of vibration than a corresponding leaf spring, by itself, this would indicate relatively higher rates of wave propagation in the coil spring. Higher velocities of propagation, on the other hand, would make a spring more suitable for rapid vibrations. If any conclusion from the experiments described were at all possible, it would be that the coil spring is better for rapid vibration than the leaf spring.

In Fig. 10 the author illustrates a lever suspension which he indicates would solve the alleged problem of spring inertia, except that the lever would break on account of the inertia forces under high accelerations. This point is worthy of further scrutiny. To carry 900 lb., such a lever, if say 24 in. long, and properly designed, would hardly weigh 32 lb. Also, its radius of gyration would certainly not exceed about 12 in. Now, let

ρ = Radius of gyration or 1 ft.

M = Mass of lever $\frac{\text{Weight}}{32} = \frac{32}{32} = 1$

α = Angular acceleration

a = Linear acceleration at end of long arm

l = Length of long arm or 2 ft.

F = Inertia force at end of long arm

According to well-known formulas,

$$M\rho^2\alpha = Fl$$

But the angular acceleration α is related to the linear acceleration a by

$$\alpha = \frac{a}{l}, \text{ hence}$$

$$M\rho^2\frac{a}{l} = Fl, \text{ or}$$

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$$F = Ma\frac{\rho^2}{l^2}$$

Putting in the values of $M\rho$ and l indicated above, and choosing for a the acceleration used in the paper, of 3888 ft. per sec. per sec., we get

$$F = \frac{32}{32} \times 3888 \times \left(\frac{1}{2}\right)^2 = 972 \text{ lb.}$$

In other words, even with the acceleration assumed in the paper, which would destroy the wheel and axle, the inertia force on the lever would be about the same as the

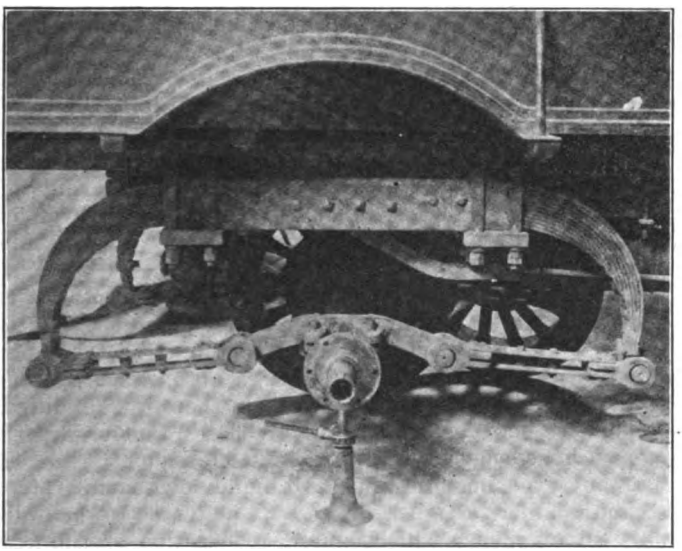

FIG. 17—A 2-TON TRUCK EQUIPPED WITH A SPECIAL TYPE OF SPRING SUSPENSION

normal load on the lever, and would be taken care of by ordinary factors of safety. In fact, lever suspensions have been built and tried out. They have not made progress primarily because they do not achieve any new result.

After the lever suspension, the author discusses what may be called suspensions proper. The use of such suspensions dates back to the stage-coach days. In fact I have seen one illustration which is taken from a British patent dated 1798. I believe there are extant in this country several examples of coaches having that type of spring support. The contention that such suspensions

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offer a saving in weight of spring material is contrary to basic principles, that the weight of a spring is determined by the amount of energy it must store, the fiber stress, the type of spring, whether torsional or flexural, and the uniformity of stress distribution, which determines the weight efficiency. Furthermore, the use of straight springs, such as shown in the author's Fig. 14, leads to an utterly impracticable design. When I laid down the design shown in the accompanying photograph, I calculated out some straight springs. But the depth of the springs came out about the same as their length, and the leaves were too thin for a practical design.

In discussing the use of curved springs in such suspensions, the author chose a rather poor example. About four or five years ago I equipped a 2-ton truck with springs built along such lines, a photographic view of which is shown in Fig. 17. There is a radical departure in this design, whereby radically new results are achieved. The outstanding structural feature is that the springs of the suspension have an initial strain which is large in comparison with the subsequent strains due to axle and body motions. See Figs. 18 and 19.

The important results achieved are (*a*) a means is provided for obtaining substantially perfectly elastic forces from an imperfectly elastic medium; (*b*) the fiber stress in the spring material, though high, is nearly constant, and breakage due to fatigue is thereby eliminated. This latter is proved not only by Wöhlers' famous experiments, made over fifty years ago and subsequently verified by many experimenters, but also by our own comparative steam-hammer test. In this test we delivered to the ordinary spring blows which caused a deflection of full-load plus 60 per cent. At 15,000 blows the spring began to fail; at 30,000 it was a misshapen mass of steel.

To the "constant-stress" suspension we delivered blows causing a deflection of full-load plus 140 per cent. At 40,000 blows a tension member broke at a rivet hole. The tension member was repaired and the spring put back on the truck. That truck is in operation today with the same set of springs. If any appreciable buckling stresses existed in this suspension, the steam-hammer would certainly have found them.

I spoke of steel as an imperfectly elastic medium. Is it? As a result of five years of observation and experiment, during the last six months of which we have had means at our disposal, through the development of the

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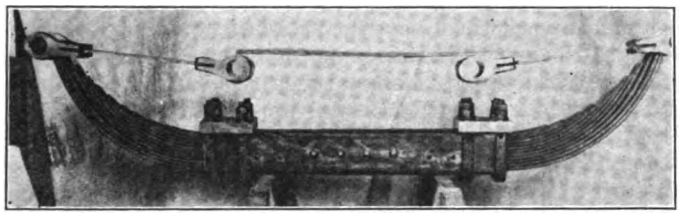

FIG. 18—TESTING THE SPECIAL SPRING SUSPENSION

seismograph, which have hitherto been unavailable, we have found that the conventional leaf spring, when properly designed, is a very satisfactory device, when new. The basic defect of the conventional spring is that it does not stay that way. And the trouble is not due to the growth of interleaf friction, so much, but to the growth of molecular friction. In short, we have found that the chief and most prevalent cause of hard riding is spring fatigue.[1]

In the "constant-stress" suspension, not only is fatigue itself minimized by the fact that the stress range is small, but also, even if the spring material should develop internal friction or hysteresis, the suspension will continue to ride with approximately perfect elasticity. This will be proved both theoretically and practically in a future communication.

In the suspension shown in the figures, we ran the maximum stresses higher than would be permissible in

[1] See article on Elasticity, by Lord Kelvin, in the Ninth Edition of the Encyclopedia Britannica, for interesting information on this matter.

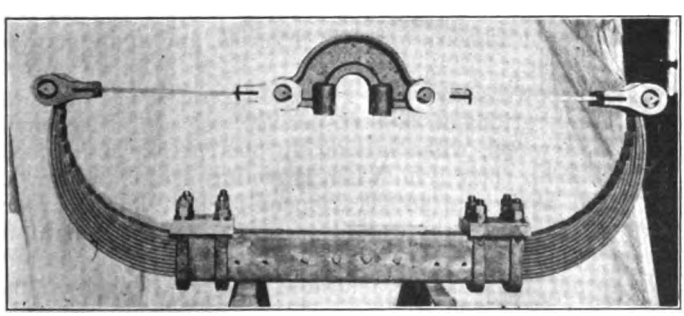

FIG. 19—THE INITIAL STRAIN IN THIS SPECIAL SPRING SUSPENSION IS LARGE COMPARED WITH THOSE RESULTING FROM MOVEMENTS OF THE AXLE AND THE BODY

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ordinary springs. Also, because the springs were designed for practically one position, we obtained very high weight efficiencies in the spring material. In consequence, the weight of spring material required was but little more than in the conventional type of spring. Nevertheless, the suspensions, as a whole, did weigh considerably more than the equipment they replaced. Furthermore, it was not always easy to find space for the spring material, and to make the design architecturally satisfactory.

Coil springs can be designed to weigh 40 per cent or less than corresponding leaf springs. We have reverted to coil springs, which we used in our first laboratory experiments, and have been thereby enabled to produce very satisfactory designs from all practical standpoints.

E. FAVARY:—Dr. Liebowitz says that I have assumed "the same spring for both large and small sprung weights." I did not make any such assumption. In my paper, Fig. 2, I show two examples, a light and a heavy sprung weight; the mass of the latter appearing to be more than 20 times that of the light weight. Would any engineer consider for a moment the use of the same spring for two weights of such disparity? I stated plainly, when describing the case of the heavy unsprung weight that "no matter how weak or strong the spring above which supports the light weight may be, it will carry the small weight along with it."

In the paper referred to, which Dr. Liebowitz read in 1916, he says that "to make the subject amenable to analysis and the results simple enough" he introduced "approximations and limitations." It is principally in this respect that our papers differ. He is thinking of the results of the mathematical analysis and uses approximations to ascertain desired results, while I analyze the problem as it appears to me in practice, and apply mathematics to it.

Dr. Liebowitz says that I have illustrated my theories with accelerations of 3888 ft. per sec. per sec. I assumed that, if a wheel, when hitting an obstruction at a speed of 49 m.p.h., rises 1 in. when traveling 4 in. forward, it will have a vertical acceleration of 3888 ft. per sec. per sec., not an impossible condition, Dr. Liebowitz's opinion to the contrary notwithstanding. I stated why I selected this rather unusual case, and how, by permitting the axle to move slightly backward, which happens in practice more or less, the upward acceleration can be reduced. Why did Dr. Liebowitz not try to disprove my figures

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from the assumed 1-in. rise of the wheel? Evidently because he cannot do so. He says such accelerations have no effect on spring design. I think they have very much to do with it, as showing what conditions we would actually get oftener if the wheel velocity were not slightly retarded as mentioned in my paper. He quotes from the laws of motion, that a force 120 times that of gravity has to be impressed upon a body to give it the acceleration I mentioned. This is true, but he misapplies this well-known fact to my example. As Mr. Huxley remarked to one of his mathematical friends: "Your mathematics is a very fine mill, but the grist you get out depends on the grain you put in."

In my example I assumed the unsprung weight per wheel to be 300 lb. This includes the wheel complete, the spring, one-half the weight of the entire rear axle and axle housing containing the differential, and a part at least of the propeller-shaft. To begin with, the center of the axle and axle housing in the center line of the car will have an acceleration only one-half that of the wheel, when the latter hits an obstruction. Furthermore, the major portion of the spring will have a lower acceleration than the wheel, since it flexes, and that part of the spring attached to the frame and immediately adjacent will have a very low acceleration indeed. The actual weight affected by the maximum acceleration is therefore in practice very likely not more than 30 per cent of the unsprung weight, when a wheel surmounts an obstruction. To find the actual stress in the wheel, there must be added that required for the mass exposed to the lower acceleration. We are therefore nearer correct in arriving at the stresses in the wheel when adding another 30 per cent to the weight, and taking the acceleration of the mass at 3888 ft. per sec. per sec. We thus have 120 x 180, or 21,600 lb.

A knowledge of the strength of wood wheels might be of interest in this connection. The University of Michigan has made tests of automobile and truck wheels,[8] but only three examples were given, the first of which evidently comes nearest to our example of carrying a load of about 1200 lb. Under direct load the wheels supported 40,800, 114,000 and 140,000 lb. respectively. In these tests the remarkable recovery of wood wheels to their original shape when loaded to almost their breaking point was noted. Hence, I believe I am right in maintaining

[8]S. A. E. TRANSACTIONS, vol. 8, part 2, p. 264.

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that the wheel mentioned in my paper would not break if occasionally subjected to a force of 21,600 lb. or even considerably more. Dr. Liebowitz not only speaks of the wheel but states that the bearings and the axle would have to withstand a load of 36,000 lb. and have a factor of safety of 30. Let us take the bearing. I surmise he refers to the wheel bearing. Here the only weight subjected to the maximum acceleration is the portion of the axle in the wheel bearing proper. The weight of the wheel and the spring does not enter here, but only that of the axle and axle housing which, as mentioned before, has at the center of gravity an acceleration of only one-half the maximum. Taking this into account, it will be admitted that the ordinary factors of safety of the bearing and the axle are sufficient, even if the wheel should on exceptional occasions have an acceleration of 3888 ft. per sec. per sec.

These periodicity experiments (See Fig. 4) were described in the paper to show how the load affects the periodicity. The weight attached to the spring, as far as the coil spring is concerned, was not of the same order of magnitude as the coil spring itself as stated by Dr. Liebowitz. I will discuss this in a later paragraph.

Dr. Liebowitz says that he went into the theoretical side of spring inertia and found that it enters very little into the problem. In corroboration of his conclusion he cites steam-hammer tests and, while admitting he did not know what the accelerations of these were, asserts "they were certainly far higher than those encountered in actual practice." He concludes the paragraph with "there were no indications that it (spring inertia) played any appreciable rôle." Such statements seem to me to be misleading. He did not look for spring inertia. He speaks of no means or devices for ascertaining it. Let us analyze the steam-hammer he mentions and find its acceleration when used to flex a spring from no load to its maximum deflection. From his Fig. 19 I assume the maximum deflection until bottom is hit to be 9 in. Judging from his figures, I take it the steam-hammer ram with piston weighs certainly not more than 350 lb. and has a stroke of 2 ft. To be on the safe side, let us assume the steam pressure behind the hammer to be 7000 lb. In such case the acceleration as the ram descends would equal

$$g + \left(g \, \frac{7000}{350} \right) = 21 \, g$$

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or twenty-one times gravity, i. e., 675 ft. per sec. per sec.

Since the stroke h is 2 ft., we have, by the well-known laws of motion, the formula

$$h = \frac{v^2}{2a}$$

v being the velocity, and a the acceleration. Hence

$$v = \sqrt{2ah} = \sqrt{2 \times 675 \times 2} = 52 \text{ ft. per sec.}$$

The maximum "give" s, from no load to maximum deflection, we have assumed to be 9 in. or 0.75 ft.; that is to say, the hammer is stopped in 0.75 ft. Hence

$$a = \frac{v^2}{2s} = \frac{2700}{1.5} = 1800 \text{ ft. per sec. per sec.}$$

This is therefore less than one-half of what it occasionally is in practice, as described in my paper. Because a steam-hammer has a very high acceleration when used for forging where its motion is stopped in, let us say, ½ in., Dr. Liebowitz evidently concluded that the acceleration must be very high when stopped by the flexure of a spring. If the hammer were stopped in ½ in. its acceleration would be about 32,000 ft. per sec. per sec. Therefore, on the face of it, his steam-hammer test is useless as far as high acceleration or spring inertia is concerned. Assuming, however, for the sake of argument, that he could obtain an acceleration as high as the figure I gave, how would this be indicated in his experiment, and how could he measure what effect it had upon passenger comfort in a car? In my paper, Fig. 5, I showed what took place in a thin spring when suddenly started vibrating. I think that this takes place in a very much smaller degree in ordinary leaf springs under very high accelerations, and I therefore said that it "would indicate that if we set the spring vibrating at a slower rate it would be more satisfactory." I finally described some constructions wherein the spring would flex at a lower acceleration even though the axle acceleration were high. Dr. Liebowitz offers no constructive criticism, but mentions the steam-hammer test of whose acceleration he admits he knows nothing, nor does he in the least indicate that he, or any other man, has ever hunted for spring inertia. He says nothing except that this is a complicated subject, that he went into the theoretical side of it a few years ago; but of proofs to sustain his allegations controverting my statements, he offers none.

Dr. Liebowitz ascribes to me statements which I never thought of making concerning periods of coil and leaf

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springs. I described certain experiments and, with the *coil spring tested,* it was found that twice the static deflection was necessary to obtain the same periodicity as that of the leaf spring tested. I have plainly shown that the periodicity of any vibrating body is

$$t = 2\pi \sqrt{\frac{\text{Resistance}}{\text{Restoring Force}}}$$

and I think I explained the matter with sufficient clarity for any one to see that the mass and the restoring force alone govern the periodicity, and I so stated in my paper. Hence, if the coil-spring weight were the same as the leaf-spring weight which affects the periodicity, not the entire leaf-spring weight, and if its restoring force were the same, i.e., if the deflection per unit load were the same, which means that the coil diameter would be unusually large, their periodicity would be the same. I wanted to bring out forcefully the lower periodicity of coil springs as used today with spring suspensions; that is to say, in coil-spring shock-absorbers, which have a smaller deflection and a considerably smaller periodicity. Dr. Liebowitz is wrong in stating that I "used weights which were smaller than the weight of the coil spring itself." The weight of the coil spring used in these experiments was 2¾ grams and that of the load 70 grams, or more than 25 times that of the spring. The coil-spring diameter was 7½ mm., and the size of the wire 0.533 mm.; the static deflection 5 in.; and the periodicity 80 vibrations per min. He says in this connection, "If there is any doubt as to the accuracy of the period formula . . . . . it can be checked on the seismograph which I have here." If Dr. Liebowitz's seismograph does not show substantially the same periodicity as that I have specified for the spring described, the seismograph is unquestionably inaccurate.

As to Dr. Liebowitz's remarks on coil springs fitted to Pullman cars, the maximum inequality of the rail surface is minute compared with that of the ordinary road surface, and the analogy does not hold good for road vehicles. In a Pullman car the total load is enormous compared with that of a coil spring, and there are a large number of short coils, short in deflection/load ratio. The longer a coil spring is, the more its tendency is to partial modes of vibration, and the greater they are.

A lever suspension has a number of defects. I mentioned only one great disadvantage. As to Dr. Liebowitz's

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mathematical proofs, let him take a sledge hammer and hit the lever, or let him place this under the steam-hammer, and he will find it will snap or bend at once. He may throw a wooden bar in the air and hit it while in the air; it will break if hit hard enough. Not even the theory of the ballistic pendulum holds good here; if it did we could so place the axis of the suspension that the axis of rotation might also be the axis of percussion, in which case it would break at some other point than the axis, but it would break. He is forgetting that there is another end to the lever, the end which deflects the spring. Let us take his figures and say that the long arm of the lever, Fig. 10 of my paper, is 2 ft. long, and the small arm 1 ft. Let us assume that the static deflection of the end of the lever attached to the axle is 4½ in. under 900 lb. of unsprung weight, as was stated. The axle will thus rise, or the body descend, 1 in. for each 200 lb. of load. Let us say that the maximum additional motion of the axle is another 4½ in., requiring the application of another 900 lb. when moved slowly. Thus, while it would take another 900 lb., or a total of 1800 lb., to move the axle up slowly, Dr. Liebowitz tells us, under a most severe shock, the stress in the lever would be only 972 lb. or, to use his words, "even with the 3888 ft. per sec. per sec. acceleration assumed in the paper, which would destroy the wheel and the axle, the inertia force on the lever would be about the same as the normal load on the lever," etc. He concludes this subject with the statement that lever suspensions have been tried but "have not made progress primarily because they do not achieve any new result." Does he know where lever suspensions have been tried and what their results have been? He speaks of none. He attempts to prove what the actual stress in the lever is without giving an account of a practical test. I constructed one experimental lever suspension in 1913 and, when testing it for rapid blows, found that it snapped. Hence, I spoke of this as the great disadvantage of lever suspensions.

With regard to suspension proper and in reference to the 1798 British patent, Dr. Liebowitz says, "I believe there are extant in this country several examples of coaches having that type of spring support." The British patent shows a coil spring in a roller around which one end of a strap is wound; as the load increases, this coil spring permits the strap to elongate. This has no bearing on present-day vehicle suspension. I should like to

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ask whether he refers to the latter type or to the type described in Figs. 13 to 15 of my original paper. The construction I have shown he then proceeds to discuss in the following words: "The contention that such suspensions offer a saving in weight of spring material is contrary to basic principles," etc., and his remark about the design of straight springs that "the depth of the springs came out about the same as their length, and that the leaves were too thin for a practical design," is remarkable. With reference to his Figs. 1 and 3, he says that he divides the spring because it saves unnecessary length of spring material. In other words, he divides the spring to save spring weight. If he thus

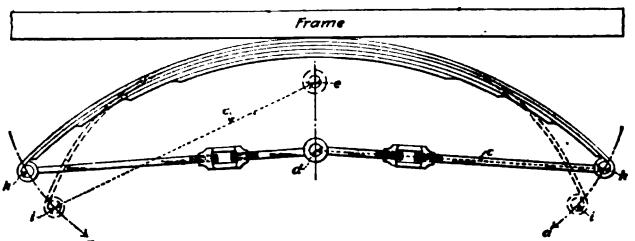

FIG. 20—SPRING SUSPENSION EMPLOYING A SEMI-ELLIPTIC SPRING

saves weight, by so much more do I do the same with my short straight spring, the tension on the spring eyes being the same. The construction shown in his figures is lighter than it would be if made with a semi-elliptic spring. By glancing at his Fig. 19, it is self-evident that if the middle portion were spring material, it would be heavier than when the spring is divided as shown. But in addition, if the spring flexed at or near the center, the number of leaves would have to be increased, since the distance from spring seat to spring eye would be greater, and the bending moment at the seat would likewise be greater. He was therefore right originally in stating that there is a saving in spring weight by dividing the spring instead of making it one continuous spring seated at the center. By going a step further, dividing it still more, and making the springs straight (see Fig. 21), the same ratio of saving continues and, in addition, it can be made lighter because the length between spring seat and spring eye is decreased still further, thus further reducing the bending moment at the seat. There is still another point worthy of notice, namely, that the flexure in the spring per unit length is

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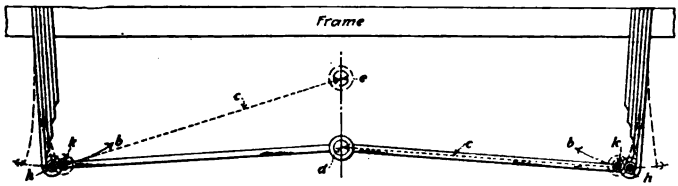

FIG. 21—SPECIAL SPRING SUSPENSION USING TWO SHORT STRAIGHT SPRINGS

considerably less, which means that a much shorter spring can be used when it is made straight. In the illustrations, Fig. 20 shows a semi-elliptic spring embodied in this type of suspension. Fig. 21 shows short straight springs, and in Fig. 22 both types are shown in one view to bring out more clearly their distinguishing features. In Fig. 22 is illustrated what happens when a semi-elliptic spring is used instead of two short straight springs. While the axle rises from *d* to *e*, the spring eye of the semi-elliptic follows approximately the path *a* and assumes position *i*. In the case of the straight spring the eye would follow approximately arc *b* and move only the short distance from *h* to *k*. Therefore the outstanding features of a straight spring over a semi-elliptic spring as well as over the constructions Dr. Liebowitz shows in his discussion are (*a*) that the spring can be made considerably lighter and shorter, (*b*) there is less flexure per unit length and (*c*) the bending moment at the seat is less. This latter varies directly as the length, if the tension and the direction of the flexure are the same. Hence, it is erroneous to say that a straight short spring does not save spring weight, and that the leaves would be too thin, etc.

Referring to the claim of the initial strain, I originally showed the spring under considerable initial tension; in fact, the construction could not work without it. In my

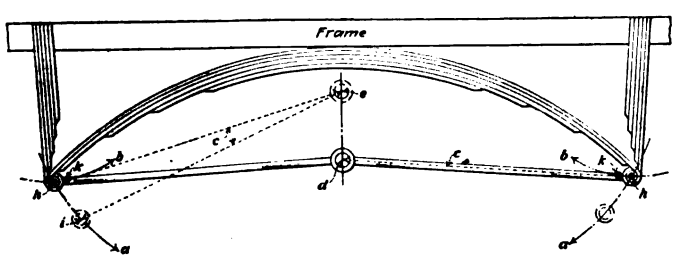

FIG. 22—A COMPARISON OF THE SEMI-ELLIPTIC AND STRAIGHT SPRINGS IN THE SAME SUSPENSION

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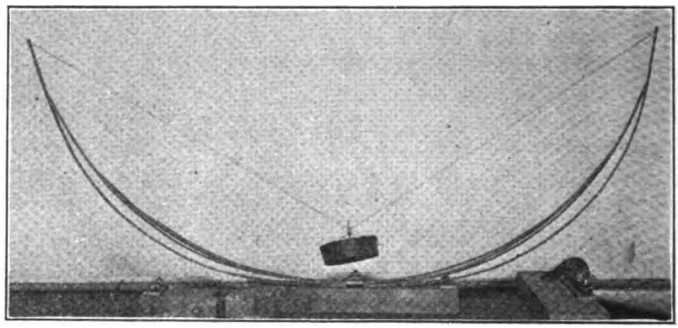

FIG. 23—BUCKLING STRESSES IN A SPRING

construction, Fig. 21, the position of the spring before being connected to the tension rods is shown dotted. Dr. Liebowitz also disputes the existence of buckling stresses to which I adverted in connection with the semi-elliptic spring when applied to this type of construction. The accompanying Fig. 23 clearly illustrates the buckling stress, and this also holds good to some degree in the structures disclosed in his figures, although much less than in the semi-elliptic.

When the springs are straight, or when they are arranged with their seats still further apart than their eyes, so as to have the direction of the force exerted on the leaves at right angle to their length, a most important matter, which is impossible of attainment with the structures he illustrates, the spring can be made considerably lighter than those he shows; the flexure per unit length is less; the bending moment at the seat is less; the spring is more sensitive, since the spring eye moves a smaller distance for a given axle displacement; and there are no buckling stresses. Another disadvantage of the construction shown by him is that the leaves are made to flex in the reverse direction from that customary with leaf springs.

Regarding Dr. Liebowitz's plea for coil springs, I fear that it will be somewhat difficult to prove the coil type of springs superior to leaf springs for use in vehicle suspensions.

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BETTERING THE EFFICIENCY OF EXISTING ENGINES

By H C Gibson[1]

First reviewing the history of the progressive insufficiency of the supply of highly volatile internal-combustion engine fuels and the early efforts made to overcome this by applying heat to produce rapid vaporization, the author gives an outline of the methods already found valuable in offsetting the rising boiling points of engine fuels and states the resulting three-fold problem now confronting the automotive industry.

The tendency to subordinate efficient vaporization to the attainment of maximum volumetric efficiency is criticised at some length and the volatility of fuel is discussed in detail, with reference to characteristic distillation, time of evaporation and distillation-temperature curves which are analyzed.

Heating devices are then divided into four classes and described, consideration then being given to fuel losses outside the engine. The use of some pressure-indicating apparatus such as a manograph, for determining pressure conditions within the cylinder, is believed necessary.

Summarizing, ten definite recommendations are made for bettering engine efficiency.

The first De Dion motor tricycles were arranged to consume a fuel so volatile that it was only necessary to bubble part of the intake air through the liquid to obtain a mixture so rich in hydrocarbon vapor as to require the admixture of further air for proper combustion. This fuel was the top of the toppings from the small quantity of crude oil then being refined, and the supply was more than sufficient to meet the demand for internal-combustion engine fuel at that time. As the demand grew, these tops were insufficient and so, when the heavier distillates of a slightly higher boiling point were added to augment the supply, De Dion installed a heater pipe in the surface carbureter and passed hot exhaust gases through it to boil off those higher-boiling-point fractions which would not, without heat, evaporate rapidly enough to provide an effective mixture.

The arrival of the atomizing carbureter called a halt

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for a time on the developments involving the use of heat for vaporization, for with the comparatively low boiling point of that day, the minute globule coming from the spray nozzle would receive sufficient heat from the air in which it was entrained, even in the short time of transit from the nozzle to the engine valve, to evaporate it. The vaporization was aided, of course, by the vacuum in the inlet pipe, which naturally reduced the boiling point of the liquid. Those of us who used "gas wagons" in 1890 to 1895 will remember that we had little thought for carbon except such as resulted from the destructive distillation of the lubricating oil which found its way into the combustion space.

The demand for fuel became progressively greater, so that with all the low-boiling-point toppings that could be saved, the refiner was compelled to throw in some of those fractions which were formerly allowed to run in with the kerosene. Then the carbon trouble began to brew and increased so rapidly that it is now almost essential to remove carbon deposits every few weeks, especially in the case of high-compression engines.

Carbon deposits represent a waste of a large quantity of gasoline, which not only serves no useful purpose but actually results in definite costly harm to the engine, in wear due to abrasion and attrition by hard carbon particles, to say nothing of the associated harm resulting from pollution and dilution of lubricating oils by raw fuels, and such products of combustion as are washed into the crankcase with the unevaporated fuel that accompanies such a condition. An outline of the methods that have been found of value in offsetting the rising boiling points of our fuels should be helpful as a guide for the more general adoption of such means as will result in increased satisfaction and profit to all motorists, whether the profit be in pleasure and recreation or of the bankable kind attainable through commercial truck or farm machinery operation. An increase of such satisfaction means the prolongation of widespread industrial activity of paramount importance to the nation, through its automotive and petroleum industries, its third and sixth largest in value of products. Every unit of these industries would feel the pinch resulting from a hurried search for fuel to substitute for the gasoline we have thrown away, while wishing for a better fuel than we now have at the price we now pay. The problem confronting the industry is threefold, involving

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(1) The physics of the carbureter, meaning the metering of a liquid into a current of air in a chemically correct quantity

(2) The physics of evaporation of hydrocarbon liquids, meaning the complete evaporation of the liquid prior to the physical mixture of its molecules with those of oxygen

(3) The physics of diffusion of gases, meaning the placing of the molecules of the vapor in close relation to their chemically appropriate molecules of oxygen, whereby inflammation may produce complete combustion with maximum temperature

These three phases accurately performed enable us to secure a maximum value from the formula

$$\text{Efficiency} = \frac{t_1 - t_2}{t_1}$$

which means that the higher the temperature of combustion at the beginning of the power stroke t_1 the less fuel we will use for the power developed. Thus, if we desire fuel efficiency, we must bend our energies to the attainment of conditions as near perfection as may be in each of the phases, for partial failure in any one deteriorates the whole effort materially.

Volumetric Efficiency

One potent deterrent to the attainment of reasonable fuel efficiency has been the tendency to subordinate efficient vaporization to the attainment of maximum volumetric efficiency, meaning maximum weight of charge per stroke. The real goal to aim at is to inspire sufficient charge to develop the desired amount of power. This conception involves a little less charge per stroke, higher-speed engines with consequent increase in number of charges per minute, better chemical composition of the charge, higher initial temperatures and pressures and consequently less fuel per horsepower.

The effort of most carbureter designers has been to give high torque at high speed, where the useful range of mixture proportions is narrow. This involved the use of more nearly chemically-perfect mixture proportions for the purpose, but still the composition generally inclines toward the rich side because full torque can be maintained with less accuracy of metering than is necessary to maintain maximum fuel efficiency.

At low speeds the range of useful mixture proportions for maximum torque is much wider, the carbureter de-

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signer takes advantage of it, and since our engines are run at comparatively low speeds most of the time our greatest consumption of fuel is generally performed with the more inefficient mixtures. This tendency of the carbureter designer is another result of our insatiable demand for extreme power output from minimum engine dimensions.

Because of the desire for high volumetric efficiency per stroke, the carbureter designer tried to avoid restriction and did avoid heat because both militated against that sort of efficiency, but every such designer will agree that, with a very slight restriction, accurate metering is possible today, and now that the permissible error in metering is more nearly established, as shown by the work done at Purdue University and elsewhere, we may look for greater accuracy and efficiency in the first phase of the problem, but not if we insist on high volumetric efficiency per stroke through the use of cold mixture. Reduced sectional area of the manifold, used for the purpose of maintaining mixture speed when a cold mixture is employed, also results in reduced volumetric efficiency.

The economical mixture is always leaner than that giving maximum torque, but the difference in torque is slight and not worth the economic loss of fuel. To make up for that difference in torque we must use slightly higher engine speeds and higher gear ratios, if we wish to maintain the rapid getaway and high car-speeds to which we are now accustomed.

The carbureter designer is not to be blamed for these uneconomical uses of fuel. His customer, the engine builder, must change the nature of his demand. It will then be met as to accurate metering for economical mixture proportion. The loss of fuel from inaccurate metering may equal the amount actually necessary for the work done by the engine, or, in other words, a 50 per cent loss of fuel may occur without noticeable effect on the torque output.

Referring to the other two phases the complete evaporation of the liquid prior to chemical combustion is of vital importance to the economical combustion of fuel, for unless it is evaporated some considerable time before the spark occurs, it is impossible to comply with the requirements of the last phase. Liquid cannot burn, it must first be converted into a gas suitable for our purpose and thereafter molecularly presented to oxygen in the correct

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quantity. These operations take time and the length of time at our disposal is in any case minute. At 3000 r.p.m., a cold fuel molecule must leave the carbureter jet, become separated from its fellows, surrounded with oxygen and ignited, all within 0.01 sec. This would be quick time for a photographic exposure, to say nothing of the physical transfer of the molecule along a path say 18 in. or more in length while undergoing a holocaust of physical transformation.

Volatility of Fuel

We are accustomed to think that gasoline is a volatile liquid, but if we would forget all about volatility in considering fuels we would arrive at a solution more quickly. When we desire to evaporate liquids, such as water in a boiler, we give sufficient heating surface, sufficient time and sufficient but not too high a temperature. We do not consider water a volatile liquid, yet about 80 per cent of every gallon of gasoline sold to the motorist will not boil at the boiling point of water. Thus from this standpoint volatility now becomes a negative term, while condensability would more nearly describe its important feature.

The following figures and curves show the difficulty of evaporating gasoline unless sufficient temperature and time are applied and allowed. Two gasolines, No. 1 a Mid-West and No. 2 an Eastern product, were distilled in the ordinary way, each successive 10 per cent of distillate being collected in a separate beaker. The time required for distillations, and the initial and final boiling points, using the standard test procedure of 2 drops per sec., were, respectively

	No. 1	No. 2
Time	25 min. 51 sec.	25 min. 18 sec.
Initial Boiling Point	149 deg. fahr.	144 deg. fahr.
Final Boiling Point	419 deg. fahr.	430 deg. fahr.

Part of each of the 10 per cent cuts was then redistilled, using standard procedure, with the results given in Table 1 on page 186.

Fig. 1 shows the normal distillation characteristics of the two gasolines, while Fig. 2 shows the time in minutes necessary to evaporate the various 10 per cent cuts at 180 deg. fahr. It is noteworthy that the final boiling point of any cut is much higher than the initial point of the next cut in the series. Figs. 3 and 4 show the

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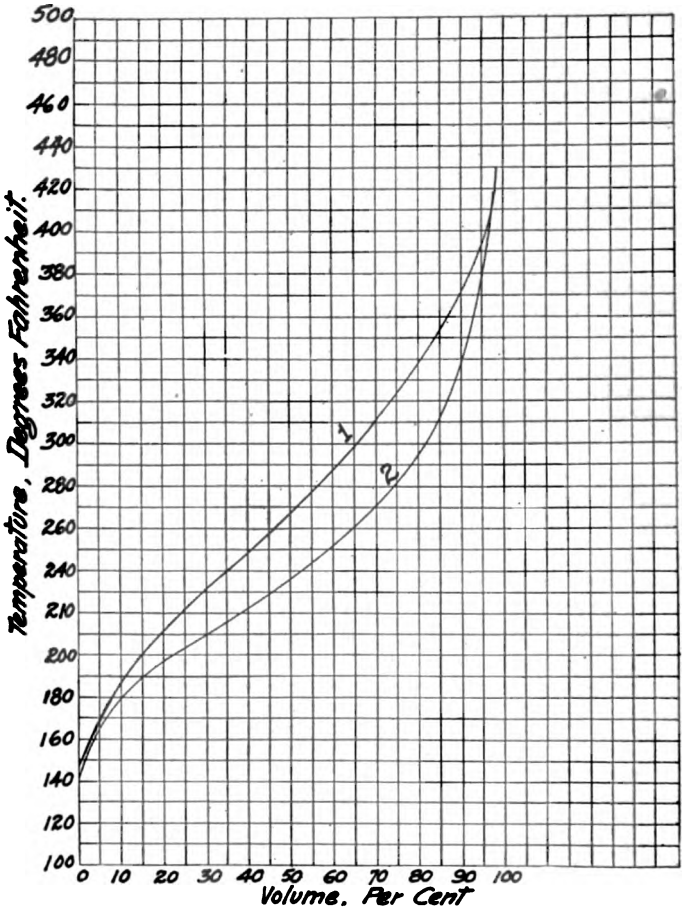

FIG. 1

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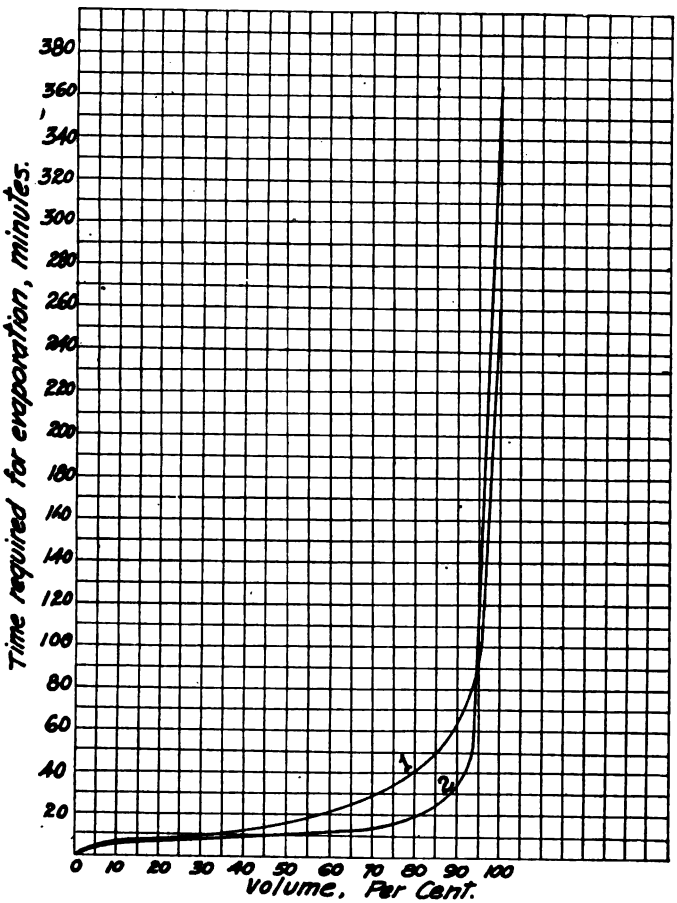

FIG. 2

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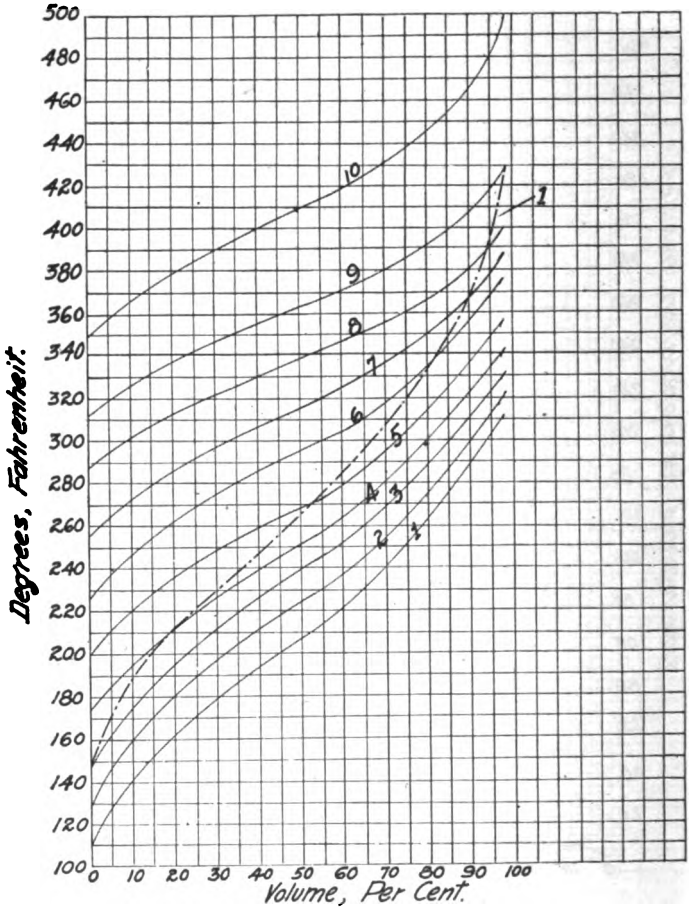

FIG. 3

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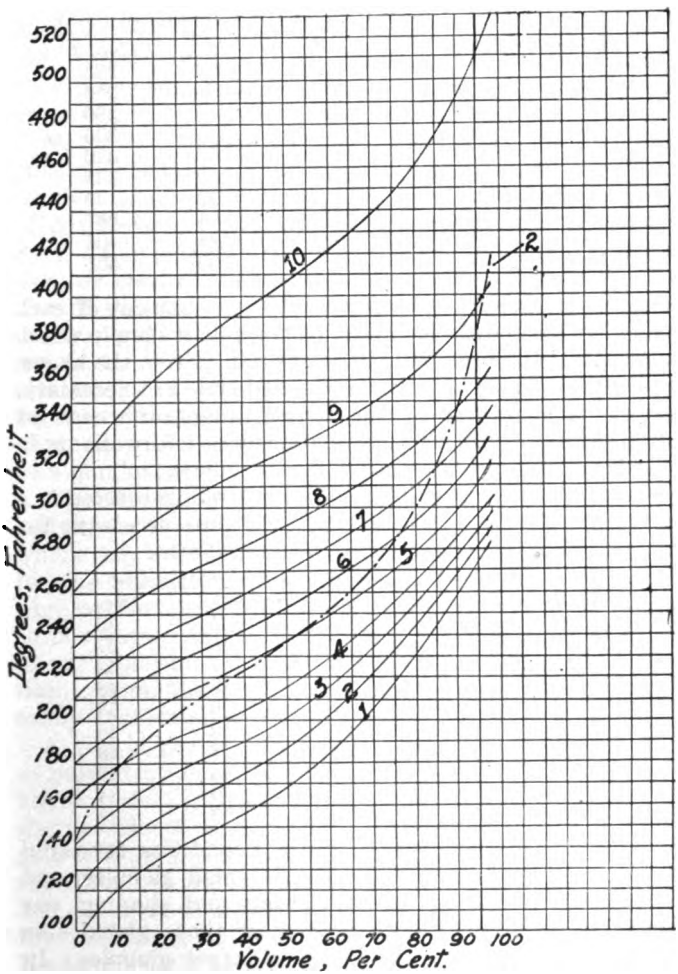

FIG 4

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TABLE 1—RESULTS OBTAINED BY REDISTILLING SUCCESSIVE CUTS OF THE ORIGINAL DISTILLATION OF TWO GASOLINES

	INITIAL BOILING POINT		FINAL BOILING POINT	
Cut No.	No. 1	No. 2	No. 1	No. 2
1	111	97	320	288
2	127	118	324	293
3	147	142	334	300
4	172	162	345	306
5	198	181	358	320
6	225	199	369	333
7	255	212	392	347
8	288	235	403	367
9	313	262	424	405
10	349	315	500	531

distillation temperatures of each 10 per cent cut of each fuel with the distillation curve of the entire sample which is shown by the broken line superposed. From the above, it is evident that much more heat and time are necessary, for the evaporation of the high-boiling-point ends of gasoline which may be deposited on manifold walls or in cylinders, than we are accustomed to allow.

Another part of each 10 per cent cut was subjected to a temperature of 180 deg. fahr. and the time necessary for complete evaporation was observed, as follows:

	No. 1		No. 2	
Cut No.	Min.	Sec.	Min.	Sec.
1	6	53	5	33
2	8	51	6	57
3	11	4	7	52
4	12	23	8	48
5	14	35	9	58
6	18	24	12	46
7	29	20	14	48
8	39	15	16	29
9	65	32	29	34
10	259	0	360	34

The carbureter puts the liquid in a condition for rapid evaporation, by breaking it up into small globules, and we ordinarily try, by proportioning and shaping our manifolds, to prevent the tendency of those globules to join with others in the formation of larger globules. In fact, we try to prevent them from following the law of nature that provides for the formation of a large drop of rain out of the assembly of a large number of fog particles. In the case of water fog in the clouds, a little local mechanical disturbance or a little drop in temperature precipitates rain. The presentation of a cold surface to a water fog results in a sheet of water. On introducing the heat of the sun, the fog disperses and the rain evapo-

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rates. A very high wind so agitates water-laden air as to prevent the formation of fog or rain drops, but it takes power to produce the agitation. We are accustomed to imitate these weather laws in the use of a high velocity in manifolds, to aid in evaporation and mechanically prevent the deposition of liquids out of the cold mixture. This takes power from the engine and unnecessarily reduces the volumetric efficiency.

We have been prone to think that if we can, by these methods, induce pulverized fuel into the cylinder our troubles are over because, so it is said, the temperature of compression will perform the evaporation necessary. Such an hypothesis neglects the resistance to evaporation, or rise of the boiling point, brought about by the rise of pressure on the compression stroke, and even if the evaporation of the fuel particles were complete at the top of the stroke, there is not time subsequent to the attainment of complete evaporation to perform the mixing operation necessary to produce a chemically perfect mixture, without which efficiency of combustion cannot be a maximum.

The physical property of gases called diffusion, their activity in thoroughly intermingling with other gases to which they are introduced, is the phenomenon relied upon for the production of an economical mixture. A knowledge of the laws of diffusion of non-homogeneous hydrocarbon vapors in air, if not fully established, is essential to our problem. It is the starting point for a full solution. Given the law, every other stage of the problem is easily conformable.

A fog is probably a perfect example of the extreme of pulverization of a liquid, but the fuel is still in a liquid state. It is unquestionably an effective stage in the process of evaporation. Whether the laws of diffusion will permit the effective intermingling of the gases subsequent to the introduction of the fog to the cylinder and prior to the application of the spark, or whether the fuel must be first evaporated is to be determined. No time should be lost in the effort.

Many kinds of apparatus have been proposed. Some are already on the market and others are in course of development that aim to improve the fuel efficiency of existing and future engines. Some have been developed for the purpose of vaporizing kerosene, but in principle they are applicable, at least to some extent, to the use of gasoline, because the objects aimed at are identical, namely, the

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evaporation of all the fuel and the formation of a chemically active mixture prior to ignition in the cylinder.

Heating Devices Classified

Those devices may be divided into four classes:

(1) Those which heat the fuel only before mixture with the air

(2) Those which heat the air before mixing it with the fuel

(3) Those which heat all the fuel and air mixture

(4) Those which heat the fuel with some air and add cold air thereafter

Devices in the first group are, in general, subject to the disadvantage that gasoline has of being composed of fractions having various boiling points. Those fractions of low boiling point will evaporate in the carbureter before reaching the jet or exit, because they are subject to the excessive temperature necessary to boil off the high-boiling-point fractions. Thus, if the fuel was heated in a common carbureter and the float-chamber was open to the atmosphere these fractions would be lost, or, if closed, they would generate pressure and thus render abortive any attempt to meter the fuel so far as the production of the correct proportion of fuel to air in the mixture is concerned.

One form of device boils the fuel by a flame, using some of the fuel for the purpose. The resulting vapors are mixed with cold air and form a fog ready for admission to the cylinders. The many variables introduced by changes in the throttle position and in engine speed necessitate the use of a number of separate mechanisms for controlling the generation of gas in proportion to the demand. The use of fuel for evaporating the engine fuel is an economic loss, later referred to in the discussion of the third class.

Regarding the second type, the common stove or oven for heating the air as it passes over the hot surface of the exhaust pipe is a step in the right direction but, as usually fitted, it is entirely inadequate, as clearly illustrated in a recent test made by the Fifth Avenue Coach Co., on its electric dynamometer, where the original small stove could maintain only 150 deg. fahr. in the air entering the carbureter at normal full load, which was maintained by a No. 67 carbureter drill size jet. By using an oven entirely enclosing the exhaust manifold, insulating

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its exterior surface with asbestos and conducting the hot air to the carbureter through a well-insulated pipe, the air entering the carbureter attained a temperature of 250 deg. fahr. Black smoke from a rich mixture resulted and on substituting a No. 70 jet for the No. 67, normal full power was attained and maintained. The saving in fuel was approximately 10 per cent. Since the company referred to now uses 1,500,000 gal. of gasoline per year, this means a saving of $50,000 per year, or $5,000 for every 1 per cent saved.

The temperature of the hot air entering the carbureter changes with atmospheric variations but more especially with the variation in the exhaust-pipe temperature and with the change of rate of flow due to throttle and engine speed variations; it sometimes fluctuates as much as 150 deg. fahr. This varies the temperature of the carbureter nozzle. A change of only 50 deg. fahr. has been shown to affect the flow of gasoline as much as 30 to 40 per cent. From this point of view, a steady temperature at the carbureter jet is one essential for economy, unless the sharp-edge or disk-type jet is proved immune to a change of fuel viscocity and is without associated disadvantages.

When the engine is accelerated it takes time to heat up the exhaust pipe to the temperature of the new condition; hence, during acceleration, the increased air to fill the demand is colder than usual. Conversely, on throttling down, the very hot exhaust pipe excessively heats the diminished quantity of air demanded by the engine. Such changes vary the amount of fuel that is vaporized and it becomes very difficult to set a carbureter so that it will not cause loading or popping back. In any case, it must be uneconomical part of the time, and in the case of city traffic this means most of the time. From this it is clear that when hot-air stoves only are used they should be arranged to furnish heat in proportion to the amount of fuel used, they should be placed as near the engine port as possible and the wall between the exhaust gases and the air should be thin, preferably having fins or pins projecting into the streams of exhaust gas and the air. The stove should present the air to a large surface of the exhaust manifold in the endeavor to attain high air-temperature under all conditions with a control to adjust the temperature of the air to the requirements of the mixture.

Devices of the third class are of the more or less

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familiar hot-spot or hot manifold type, in which the heat of either hot water or the exhaust gases is applied to the surfaces of the inlet manifold. Hot water is entirely inadequate, for its temperature cannot be above 200 deg. fahr. and it is already shown that this temperature can do no more than boil off about 20 per cent. of the gasoline passing through the manifold.

Hot exhaust gases are the logical source of heat for the purpose, because their range of temperature will not fall below about 450 deg. fahr. while under load they will rise to about 1500 deg. fahr. If unused, their heat is a total loss amounting to some 40 to 50 per cent of the total heat value of the fuel. With such a source of otherwise waste heat, it seems unnecessary to burn any fuel specially for evaporating the engine fuel as is done in some forms of carbureter.

The normal variation of exhaust-gas temperature broadly follows the demand for power, but for a given volume of mixture flowing to the engine per minute, calling for a definite amount of heat for the vaporization of its fuel content the heating surface may be under either of two extreme conditions; one, in which the engine is racing under no load and delivering most of the fuel heat to the exhaust and so to the fuel-heating surface, or the other, in which full torque is being delivered at low speed and a minimum proportion of heat is available for the fuel-heating surface. In the first case, high vacuum in the inlet tract aids vaporization, while this condition is absent in the second case. If the heating surface is proportioned to fit the second case, a highly attenuated mixture, skipping and backfiring, will attend the first condition, especially if the carbureter is adjusted to furnish an economical mixture under load.

As in the case of the air-heating stove, a more rapid reaction to the change of throttle is obtained when the mixture-heating surface forms a part of the exhaust manifold, the wall being thin and studded or ribbed on both sides so as to readily absorb and distribute the heat to the mixture. One investigator finds that with a direct transfer of heat through one wall, 1 sq. in. of surface suffices for each 27 cu. in. of nominal piston displacement while if the exhaust be piped from the manifold to the heater 1 sq. in. of surface will be necessary for every 18 cu. in. of displacement. The latter design involves a much greater mass of material and is comparatively sluggish in its response to a change of condition.

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All the devices included in the third class should also be arranged with means for maintaining a constant temperature of the mixture and, in addition, those surfaces upon which the liquid fuel impinges should be prevented from ever attaining temperatures much above the end boiling point of the fuel or cracking of the fuel with consequent deposition of carbon will result.

The last class includes arrangements which mix some air with the fuel and subject that very rich mixture to comparatively high temperature by passing it through a tube or similar device, usually surrounded by hot exhaust gases. The liquid is partially or completely vaporized, according to the exhaust temperature applied and the time allowed. The resulting vapor and air mixture is later mixed with appropriate quantities of cold air, usually resulting in production of a fog mixture for use in the cylinder. The controlling factors of these systems are similar to those of the other three classes. In addition, the high temperature to which the comparatively small heating unit is subjected causes cracking of the fuel and the deposition of carbon therein; the small passages easily become choked, while the carbon on the heating surface acts as a heat insulator, thus varying the rate of vaporization at any given temperature of the exhaust gases. The degree of vaporization and the proportions of hot mixture and cold air being thus varied, inoperative leanness of the mixture is eventually produced. Means for controlling the temperature applied to the heating unit are desirable.

Losses of Fuel Outside the Engine

Much evaporation takes place in handling and transporting fuel, and more occurs while in the tanks and carbureters of vehicles because of the temperature and agitation to which the fuel is subjected. The least loss from this source occurs with vehicles arranged for pressure feed, inasmuch as the only point at which the gasoline is exposed to the atmosphere or can evaporate is at the carbureter, and then only if it is of the float type, having a float-chamber vent. The warmer the gasoline in the float-chamber and the more it is shaken through the vibration of the vehicle, the more evporation will take place. This loss alone may be several per cent. The next most important loss occurs in the vacuum tanks now in common use. They are usually placed on the front

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of the dash and receive a great amount of heat from the engine.

The most serious loss is in the escape of gasoline vapor from gravity tanks vented to the atmosphere. These are usually found under the driver's seat, or in the cowl, and they receive much heat from the engine, which, combined with the action of waves of gasoline surging back and forth and forming a kind of surf, present ideal conditions for evaporation.

In the tests made by the Fifth Avenue Coach Co., losses of from 6 to 8 per cent occurred in the tank alone, the variation being due to a change of the atmospheric temperature. Such a loss, added to that of the carbureter, aggravated by the inclusion of casinghead gasoline in the fuel and by the extreme atmospheric temperature of summer, may readily amount to 10 per cent which would represent, in the case of that company, a direct financial loss of $50,000 per annum, and a far greater economic loss to the community.

Such liquids as find their way into the cylinder and are unevaporated, at least in some part, get past the piston rings and, by dilution, thin the oil on the cylinder and piston walls and in the crankcase, thus destroying the lubricating quality of the oil. The usual method adopted for offsetting this condition is to use oils of a much greater viscosity than is necessary for the lubrication of the engine, with the intention that the average condition of the oil when diluted to some extent shall be about right. The method is poor, but so long as we allow this condition of dilution we have no alternative. It is wrong, first, because a blend of carefully constructed lubricating oil with kerosene is not a perfect lubricant and, second, because when the oil is first put into the engine it is too heavy and absorbs considerable power in overcoming fluid friction, whereas, after it has become dangerously diluted, rapid wear of the engine parts takes place, absorbing power uselessly and destroying the value of the engine.

The losses in connection with the dilution of lubricating oil are of general economic nature, principally in increased cost of upkeep and depreciation of the engine.

Various fuels, if vaporized and mixed with air in chemically correct proportion, have characteristic temperatures at which they will unite with the oxygen of the air and burn. This temperature appears to be little affected by the pressure at which the mixture is held.

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According to Holm, the following are the temperatures for various fuels:

FUELS	DEG. CENT.	DEG. FAHR.
Coal Tar Oil	580	1,076
Benzol	520	968
Ethyl Alcohol	510	950
Gasoline	415	779
Kerosene	380	716
Gas Oil	350	662

Because the pressure of compression gives us a corresponding temperature of the compressed mixture, it is impossible without preignition to employ a compression which raises the temperature to 800 deg. fahr. when we are using kerosene as fuel, whereas if we used benzol we could safely have a temperature of 900 deg. fahr. through an increase of compression. When the above tests were made, certain standards of gasoline and kerosene obtained, but today "gasoline" means more nearly what "kerosene" meant then; consequently we must use compressions whose corresponding temperatures are low enough to avoid automatic ignition of the mixture of kerosene vapor and air, or lower than 716 deg. fahr.

Much has been said about the formation of detonating compounds from the fuel and of the knocking which results therefrom, but I submit that the formation of a true gas prior to its entry into the cylinder eliminates this difficulty, while the admission of liquid fuel in any form to the cylinder predisposes to cracking of the fuel and the production of uncontrollable detonations; in any case detonations are not a major factor in our problem.

The situation, I consider, is as follows:

(1) Eliminate the liquid fuel from the cylinder and the detonations disappear

(2) For all practical purposes, it is automatic ignition which produces engine knocking and the loss of power and flexibility which results therefrom

(3) Reduce the compression to the point where the resultant temperature of the mixture will not cause auto ignition or alternatively, if it were possible, use fuel of a higher auto-ignition temperature-point and preignition disappears

Given an engine having a compression pressure which, under heavy load, causes preignition when using modern

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gasoline, we then have difficulty in hill climbing and poor flexibility, necessitating that it be nursed through any change of operating conditions. Such an engine is unsatisfactory to the driver and uneconomical in all respects. Feed such an engine with fuel of a higher auto-ignition point, and such difficulties disappear. On a recent test in which the fuel used was two-thirds gasoline and one-third benzol, in an eight-cylinder car having no provision for heating the mixture except a hot-water-jacket on the intake manifold, knocking was entirely eliminated, the speed increased from 30 to 35 m. p. h., and the car easily started on high gear, from rest, on the steepest pitch of a difficult hill, on which the tests were conducted. The car showed inferior general performance with gasoline, due to knocking and consequent loss of power. The benzol mixture required no "nursing" of the car; it could be handled most crudely as to spark and throttle position. Such a mixture has been found to give a miles per gallon increase of 25 per cent over that of straight gasoline in general testing through average city traffic and on open country roads.

With the compound fuel the mixture was comparatively cold when entering the cylinders and therefore, at least as to the gasoline portion, was predisposed to cracking and detonation, yet no noises could be heard. The engine was as noiseless as an eight-cylinder poppet-valve engine could be. On reverting to straight gasoline, all the old noises, difficulties and losses returned. Having raised the temperature of auto-ignition, the coincident troubles disappeared.

The corollary is that if we must use high-boiling-point gasoline, or perhaps part kerosene, with its characteristic low temperature of auto-ignition, we must resign ourselves to the use of lower compressions to avoid pre-ignition. Theoretically, we wish to avoid this expedient; practically, we must do it.

Having gasified our fuel with heat and correctly proportioned the mixture chemically, and therefore having predisposed it to knocking due to the temperature of compression, the compression to be used will be determined by the auto-ignition point of that mixture. The mixture characteristics are determined by the characteristics of the gasoline and hence we must use a compression low enough to permit the use of the worst fuel that may reasonably be expected to be available for a number of years to come.

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Use of Indicators

Builders of engines should install means for examining the net performance of the mixture-making apparatus, as measured by the results produced in the temperature and pressure of combustion within the cylinder. Most arguments and analysis on this subject stop short of the final answer; they carry us through physics, chemistry and metaphysics, but if the engine does not perform as expected it is due always to something else, whereas we should seek the truth in the cylinder. In short, everyone who desires to study the subject thoroughly should learn pressure conditions within the cylinder by using some pressure-indicating apparatus such as a manograph. No high degree of satisfaction can come to the automotive manufacturer in bettering the efficiency of existing engines, including those to be produced within the next two years, without such an instrument.

All those who have made real strides in this art have done it through and with such an instrument, and they will reap a proportionate reward for their perspicacity. Without it, steps can be taken and advances made, but they are the toddles of a child compared with the accomplishments of an athlete.

Some may think that the power delivered to a dynamometer or evidenced in the hill-climbing ability of a car are the really practical measures of the advantages gained by the application of a novel device in carburetion, but no accurate data for our purpose are thus obtained, for the reason that, while the combined effort of all cylinders of a multi-cylinder engine may show an improvement over past performances, it may well be that 75 per cent of the cylinders are doing better work, while the remaining 25 per cent are even worse producers than formerly and are a drag on the combination. In teamwork no member of the team must lag and each component must be examined for individual efficiency. In our problem this can only be accomplished through instruments capable of telling a true story about each member of the team, thus eliminating all argument that poor oil or improper this or that may account for discrepancies.

For bettering the efficiency of existing engines, the logical procedure is as follows:

(1) Take gasolines from various sources having an end-point say 100 deg. fahr. higher than we use today, make chemically correct mixtures in the test bomb and

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experimentally determine the auto-ignition points of our future fuels

(2) Adopt compressions in engines now being produced which will not result in auto-ignition even when the temperature of the mixture, due to evaporating apparatus, is high.

(3) Adapt evaporating apparatus to engines now in production for heating the mixture between the carbureter and the engine to such a point that the diffusion of the fuel gases and the air is complete before the spark is applied. Arrange to furnish such evaporating apparatus and special pistons or connecting-rods for compression adjustment for engines now running, where their number is high enough to warrant such provision

(4) Adopt means for heating the air going to the carbureter so that it maintains a fixed temperature in general operation

(5) Adopt means for automatic control of the temperature of the mixture

(6) Adopt carbureters giving accurate metering throughout the ranges of engine speed and throttle opening

(7) Adopt provisions in the carbureter to produce intense agitation of the fuel particles during the starting period only when the engine is cold

(8) Avoid evaporation of the low-boiling-point fuels through the vents of gravity or vacuum tanks or carbureter bowls

(9) Arrive at all determinations with the aid of a manograph, thus reading the ultimate answer directly from the pressures produced in the cylinders avoiding the confusion of facts with appearances which always results when the basic factors are not readably before us

(10) Educate the public to avoid impatience when starting and to allow sufficient time for this operation, thus avoiding improper readjustments of carbureters and uneconomical use of fuel

For confirmation of some of the engineering facts herein presented reference should be made to papers presented by Herbert Chase[2] and by Dr. Lucke[3]. These papers are full of the meat of the situation. They are strongly

[2] See S. A. E. TRANSACTIONS, vol. 7, part 2, page 140.
[3] See S. A. E. TRANSACTIONS, vol. 11, part 2, page 118.

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recommended as good reading. The present paper merely titrates a little pepsin for digestive purposes.

THE DISCUSSION

F. C. MOCK:—Discussions of intake-manifold design can only be profitable when they speak in definite terms of conditions that actually exist. Just now each engineer has his own idea of what constitutes a successful design, and yet all the different designs we have been able to test have given best results, for a standard grade of fuel, when brought to practically identical mixture and temperature conditions.

One designer advocates "no heat," but concedes that his car operates best on a fine summer day; another advocates "a lot of heat" and points to his flexible and economical operation in cold weather, but does not say much about pulling through sand in August. But when we put a pyrometer in the intake manifolds of these respective cars, we find that at the time of their admittedly best performance, on the same fuel, they will have come to practically the same mixture temperatures, probably within 20 deg. fahr. It all narrows down to the grade of fuel, the mixture temperature and, to some extent, the method of heat application. What we should do is to decide upon the grade of fuel we must prepare to use, find experimentally what temperature conditions will give proper operation with this fuel, and then design the car so that these mixture conditions can be maintained under the year-around, country-wide service American cars must give.

C. F. KETTERING:—I do not believe that the knock is in most cases the result of incomplete vaporization, as Mr. Gibson stated. Our indicator showed here today that the knock may or may not be due to that. There are certain conditions under which, apparently, the lack of vaporization is the cause.

We put ether in that engine today to demonstrate what we thought about it, and the indicator answered back what we thought about it. I agree that whenever we find a dozen and one remedies and half a dozen panaceas, there is just one answer, and that is that no one knows anything about it. In these discussions we are all hitting at this thing from different angles; I know that a year hence, when we return here and discuss this matter, we will have some real facts.

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Mr. Gibson says that we ought to force each manufacturer to put something on his car to give better fuel economy. That is perfectly fine, but you must understand that these cars run all the way from Florida to the North Pole, under all sorts of varying conditions, and we have not yet struck the mean average where we can do something and do it constructively. Mr. Gibson is doing a good work by taking the specific problems and fitting them to the conditions here. We must begin to do many things; finally, the general solution will come and it will be applicable. When it does, it will be so simple that we will wonder at our former anxiety.

THOMAS MIDGLEY, JR.:—With regard to the relation of volatility to knock and the resultant discussion, I have some indicator cards here and will show you some results. Regarding this subject, we find that when we look back over the records we obtained, we have some peculiar confirmation which is at the same time closely associated with this problem of volatility. I have here a card made with ether, which caused knock during the demonstration. It is a very volatile fuel and if this propagation wave is set up in it, we get typical cards when running on ether that have just one kick, a very high kick that makes much noise, but there is only one of them. As we run other fuels that will give the same knocking property, as in the case of the kerosene running up in volatility, we can imagine that the wave of detonation passes through the mixture, which has not been properly volatilized for combustion, and find that a card from kerosene has a lower initial kick than ether, but that it records two kicks on the indicator. This shows that we have a first wave passing through and then, as Dr. Dickinson suggested, another wave coming back. Passing on up the scale of volatility to fuel oil, which is still less volatile than kerosene, the indicator shows a still lower initial kick than the kerosene, but it shows the presence of three succeeding kicks. I think that is a fairly good representation of the relationship of volatility to knocking; it is not the primary cause of the knocking, but it enters in by increasing the number of these little kicks, all of which come so closely together that they sound as if they were simply one knock.

A. M. WOLF:—Mr. Gibson and Mr. Vincent have brought out the variations in exhaust heat due to variable load and speed. It will be seen that this heat is furthermore dependable upon carburetion, ignition, etc.

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By "carburetion" is meant the entire process, starting with the carbureter, until the mixture is fired. This includes distribution through the intake pipe, valve-timing, and gas flow past the valves and into the cylinder. Various locations of the spark-plug, and the shape of the combustion chamber, water-jacketing and valve-timing, all influence the temperature of the exhaust gases. They are at the extreme end of the numerous processes that occur, and any variation in any one will affect the heat. Due to the wide variation, it is necessary to closely control the heat.

I agree with Mr. Gibson that the fuel should not be heated to a point where trouble due to evaporation may take place. I do believe, however, that whether the fuel is heated to some extent or not, its temperature should be maintained within a very close range. Controlling the heat of the in-going air does not seem to me to be sufficient. The temperature of the carbureter body and the fuel within it should be closely controlled. If we design a carbureter to handle a particular fuel, the jet sizes are proportioned accordingly, assuming a fixed viscosity of the fuel. A wide variation in the temperature of the fuel will nullify all our calculations and the flow through the jets will change. If the fuel cools, the viscosity will naturally become greater and the flow through the jets will be diminished, due to the added internal friction of the fuel. This, of course, applies to the lower grades of fuel, which, as we go down the scale, show a greater change of viscosity for a given change of temperature. In making measurements with various scientific instruments, we always define the temperature at which the measurements were made, and in a great many instances this temperature is standardized. With this same form of reasoning in mind, we must maintain the temperature of the fuel in the carbureter within a fairly close range of temperature, to get suitable operation of the engine regardless of outside temperature changes. The carbureter is a metering device, as is the Saybolt viscosimeter. Temperature is as important in a carbureter as in the latter device. While fuel-injection engines are usually of the slow-speed type, the same thought applies, due to the variations which would occur with changing viscosity when the fuel passes through the pump and spray elements. As such engines become more flexible, the greater will be the need for temperature control of the fuel. It will be interesting to note the actual change in

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viscosity as indicated on the Saybolt universal instrument. These figures were obtained from Texaco water-white kerosene of 43.5 deg. Baumé.

Temperature, deg. fahr.	0	32	50	70	100
Viscosity, sec.	47	38.8	36.7	35.2	33.6

While I do not know of tests having been made to determine the restriction to flow through the jet which will occur, due to the metallic contraction of the jet nozzle as the temperature lowers, the above figures give an actual idea of temperature-viscosity effect on an orifice.

As stated before, the subject of carburetion covers the period from the time the fuel enters the carbureter until it is exploded within the cylinder. It is even hard to confine carburetion within these limits, because we can consider the removal of the burned gases as having their influence upon carburetion. While the exhaust gases form a distinct subject, they nevertheless overlap carburetion to some extent and it is necessary, therefore, to consider the successful engine as being one in which the many operations that occur within it overlap without interference, and the process of cooperation is as vital as in anything else.

We have heretofore considered the subject of carburetion too much apart from the engine itself, and means for bettering the efficiency of existing engines lie, to a large extent, within the engine itself. Mr. Trego's paper consisted chiefly of the subject of carburetion, and the title of his paper is significant in that he does not call it Carburetion but Needs in Engine Design. It was brought out that there are varying depressions in the different branches of the intake pipe, and herein lie means for bettering efficiency. The intake pipe should insure constant velocity of the mixture, and it should be of uniform section. It should also be free from sharp bends which, by centrifugal force, throw the globules out of the center of the mixture stream. The I-head engine has in its favor the fact that there are two less changes in direction of the flow of the mixture into the cylinder than would occur in the same distribution system of an L or a T-head engine. When the mixture passes by the valve head, it enters directly into the cylinder in the I-head engine. In the L or the T-head, after the gas has flowed past the valve, it changes its direction usually 90 deg., and then another 90 deg. into

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the cylinder. A great many L-head engines require seven changes in direction for the mixture after it leaves the carbureter; others have six. In the I-head engine we usually find four or five changes of direction and it is possible in this type of engine to reduce the number to three. This is one factor in favor of the I-head engine. It is an interesting fact that on some engines of the L-head type not only are there seven changes in direction of flow which ordinarily can be made of small resistance due to easy curves, but that some manifolds require an absolute reversal in direction in the flow of the mixture, and sometimes these bends are exceptionally sharp. By "entire reversal of flow" is meant that the mixture travels back in an opposite direction from which it came.

In the L or the T-head engine we have the conventional valve-pocket. "Pocket" is a very good term to describe the deficiency of this combustion-chamber space. In the cross-section of an engine we have usually made the valve-pocket height very small, and the roof is usually level with the roof of the combustion chamber or slightly below. When the valve opens we do not have a full flow past the valve head, such as is assured in ordinary calculations. Due to the poor pocket design, most of the flow is under half of the valve head. This is furthermore accentuated by the closeness of the vertical wall of the pocket to the edge of the valve head, and some engines show such a small distance at this point that the efficiency of the flow around the valve near the vertical wall is very low. In the ordinary L-head engine the vertical wall will usually follow the valve head over a sector of 120 deg., and it is therefore vital that sufficient clearance be allowed at this point. It is necessary that the old pocket be eliminated altogether, and that we forget the old form of combustion chamber. The space over the valve should be the highest portion of the combustion chamber, with the roof over the piston sloping off gradually until, at a point across from the valves, the height is lower than at any other point. It is noted that engines are just beginning to come through with this feature incorporated.

In referring to the angular distance in which the vertical wall of the combustion chamber follows the valve of an L-head engine, the I-head engine offers the advantage that the valve is practically tangent to a large circle representing the diameter of the combustion chamber,

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and therefore the angular distance offering resistance to flow past the valve is materially less.

Other than the reversal of flow which occurs in an intake pipe, and the various resistances offered in the pipe due to change in direction of the pipe itself, we also have in the multi-cylinder engine having six or more cylinders the fact that one cylinder tends to rob the other when the intake periods overlap. In six-cylinder construction we recognize the overlapping of the exhaust-pipe valves and conduct the gases away in order to avoid "backing up" in one cylinder from the other. It seems that in regular automobile design on such engines we should provide multiple carbureters as is done in racing and aeronautical work.

The water-jacket intake pipe or manifold within the cylinder-block can well be relegated to the past, along with the unjacketed, frosted manifold, for the reasons that Mr. Gibson has brought out. In the application of an external manifold, however, the designer has been less thoughtful of eliminating the sharp bends, and more thought must be given thereto. A statement was made during the discussions that the external manifold is desirable in order that the engine of the future can remain the same by replacing the old external manifold. This, to my mind, seems a temporary expedient only, in that an engine to handle low-grade fuel must be built within itself apart from the intake pipe, to handle it. In other words, we must build the engine around the fuel and not try to adapt the fuel to the engine by means of an intake pipe.

H. C. GIBSON:—I think Mr. Kettering gave the impression that my suggestion was that manufacturers be forced to put such devices on their engines. I did not even hint such a thing. My suggestion was that manufacturers be urged to use indicating apparatus and investigate for themselves. I would not try to force them to do even that.

The consensus of opinion expresssed in the discussion of my paper appears to be that the problem of Bettering the Efficiency of Existing Engines is practically the same as that of Bettering the Efficiency of Future Engines and that it narrows down to the very simple statements that

(1) Evaporation of the fuel is essential

(2) To attain adequate evaporation without partial destruction of the fuel requires maintenance of

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definite temperature in each contributory process of evaporation

(3) The requisite temperatures must be maintained automatically, indicating the use of thermostats

(4) Although existing engines have limitations due to design, nevertheless their fuel efficiency, life and dependability, can be vastly improved

(5) The application of the necessary principles to the future engine is a simple matter as has been cleverly brought out by Mr. Wolf

ALUMINUM PISTON DESIGN

By E G Gunn[1]

The two broad divisions of aluminum pistons from a thermal standpoint are those designed to conduct the heat from the head into the skirt and thence into the cylinder walls, and those designed to partly insulate the skirt from the heat of the piston head. Pistons of the first type seem logical for heavy-duty engines; those of the second type are better suited for passenger-car engines. The objections of wear, piston slap, excessive oil consumption and crankcase dilution are stated as being the same for aluminum as for cast-iron pistons; and these statements are amplified. Piston slap is next considered and, as this can be overcome by using proper clearance, pistons of the second design tend to make this condition easier to meet. Many tests show that when too much oil is thrown into the cylinder bores, tight-fitting pistons and special rings will not completely overcome excessive oil consumption. Some details of the facts thus demonstrated are given and the conclusion is reached that more rapid wear follows crankcase dilution.

There is such a wide difference of opinion concerning the fundamental theories that we may expect and do find a great difference in the design of pistons now used in internal-combustion engines. We find long pistons, short pistons, some with the piston-pin near the top, some with the piston-pin near the bottom, thick heads with cooling ribs and thin heads with no ribs.

[1]Engineer, Packard Motor Car Co., Detroit.

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From a thermal standpoint aluminum pistons may be broadly divided into two classes:

(1) Those designed with the object of conducting the heat away from the head into the skirt and thence into the cylinder walls
(2) Those designed with the object of partly insulating the skirt from the heat of the piston head

Those in the first class are usually more or less conventional in design except that they have thicker walls,

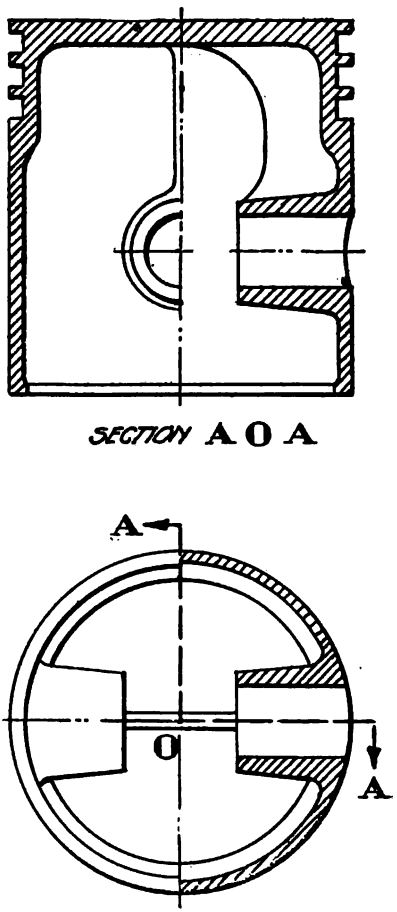

FIG. 1

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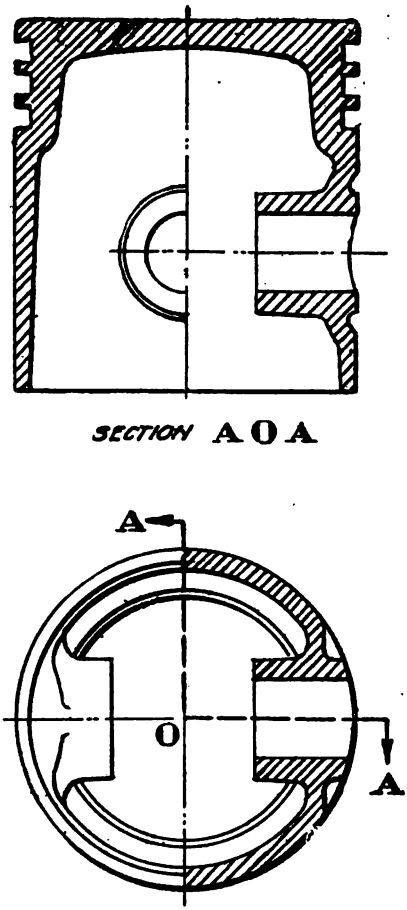

FIG. 2

or ribs extending down from the head. They are generally used for high-duty engines. In these engines, which are usually of a rather large bore and comparatively low speed, the weight of the piston is secondary to its ability to keep the head from overheating, and piston slaps are not of much consequence. Therefore, for heavy-duty engines pistons of the first type seem logical. A sketch of some of the types which come under the first group are given in Figs. 1, 2 and 3.

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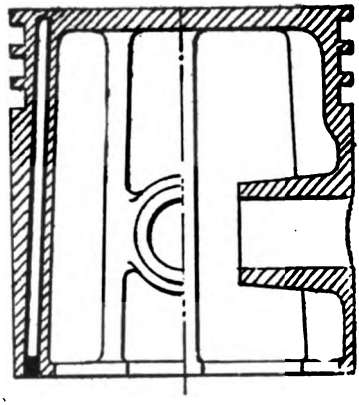

FIG. 3

PASSENGER-CAR ENGINES

For passenger-car engines the conditions are somewhat different. The duty is lighter and the bore usually smaller. This lessens the tendency toward excessive heat. Quietness being important, close-fitting pistons are desirable. Need for good accelerating ability and smoothness in operation makes lightness desirable. These considerations have led to much development work on pistons of the second type. The plan followed in most cases is to

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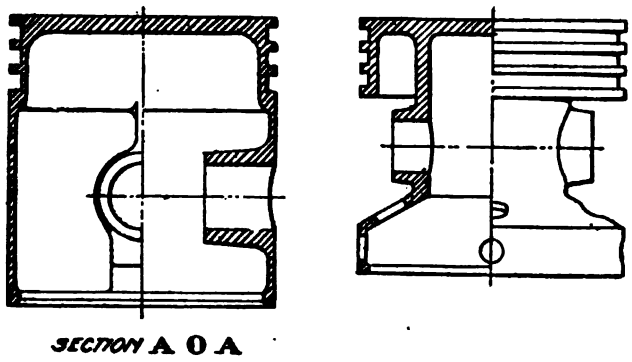

FIG. 4

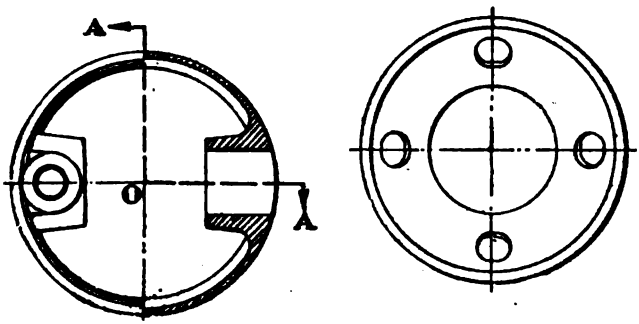

FIG. 5

partially insulate the skirt from the piston head, thus minimizing the expansion of the skirt due to heat. Some of the ways of accomplishing this are shown in Figs. 4 to 11, inclusive.

Pistons of the Long and the Franquist types are split to allow the piston to spring. They can for this reason be fitted more closely than the more conventional types. The conventional type with the comparatively thin wall is probably the most popular and for the smaller bores serves very well. It is simpler and somewhat cheaper to make than other types. In all the other types shown there has been an attempt to insulate the skirt from the head. This allows the piston to be fitted more closely, thus minimizing piston slaps.

Four points are often brought up as objections to the

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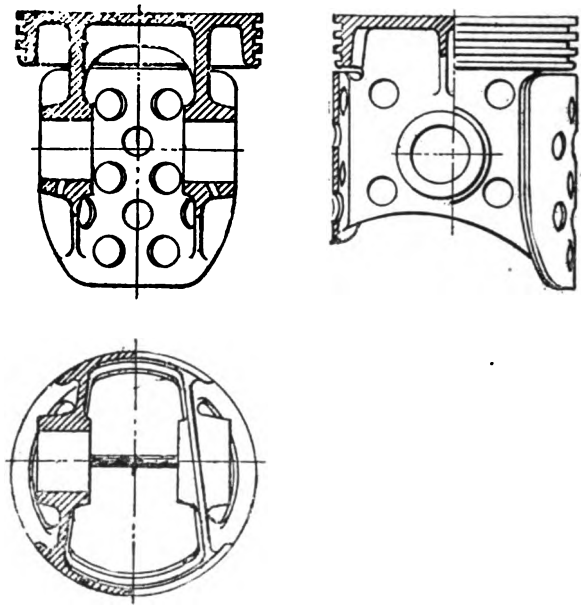

FIG. 6

use of aluminum pistons. These objections are the same as those encountered in the use of cast-iron pistons.

(1) Wear

(2) Piston slaps

(3) Excessive oil consumption

(4) Crankcase dilution

Wear has been shown to be largely a function of original smoothness. It is unreasonable to expect long life when aluminum pistons are fitted to cylinders of relatively hard material having a rough bore. Aluminum has been shown to be a good bearing metal, but it must run on a smooth surface, as in the case of babbitt metal. Much attention is paid to polishing the journals of a crankshaft, but we often see cylinder bores, whether ground or reamed, which are so rough that they can be marked with a lead pencil, although they may appear to

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be smooth. This is undoubtedly the cause of a great deal of initial wear on aluminum pistons. When cast-iron pistons are fitted this is not so evident. Dust in the air also plays a very important part in wear. Engines run on the dynamometer give much longer service than engines in cars.

I have lately examined a truck piston with the top ring worn nearly in two, and with over 1/32-in. side clearance. The rings and piston were both polished and showed no sign of scoring. This same model has repeatedly stood the same number of hours' running on test with wear so slight as to be hardly measurable. There is no question that an efficient air-cleaning device would greatly prolong piston and cylinder life.

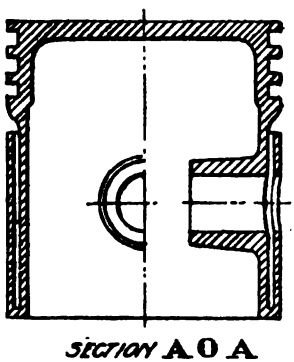

FIG. 7

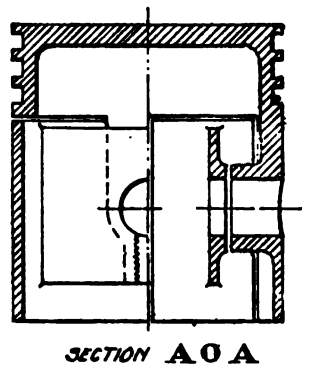

FIG. 8

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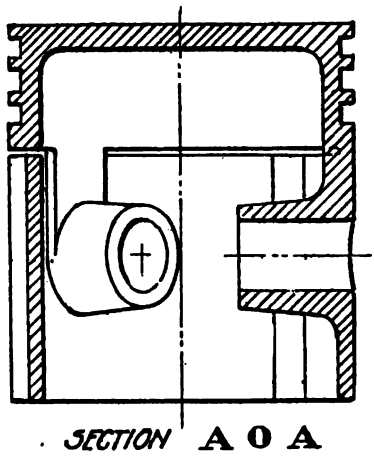

FIG. 9

PISTON SLAPS

Piston slaps can be overcome by using proper clearance. Pistons of the second design tend to make this condition easier to meet. Offsetting the piston-pin also tends to reduce piston slap. With 3½-in. and smaller bores there should be no trouble due to sticking with pistons of the conventional design fitted closely enough to prevent slaps, provided the piston and cylinder are of proper design. There should be no local hot-spots, and care should be

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taken in the design to prevent a condition tending to warp the cylinder when heated. Much trouble was experienced with sticking aluminum pistons in a certain inserted-sleeve engine of about 3½-in. bore. The cylinder was in the form of a block aluminum casting, with inserted cast-iron sleeves. Clearances up t 1/64 in. were tried, but still the pistons seized. The sleeves were removed and found to be machined so that there was an air-gap of 0.005 in. between the sleeve and the cylinder

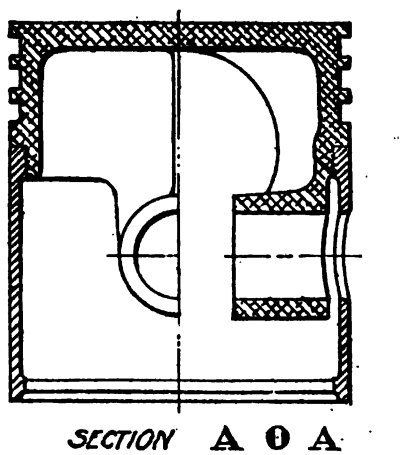

FIG. 10

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wall. These sleeves were replaced with others which fitted all the way down, and pistons with 0.007-in. clearance were then found to be satisfactory. This is perhaps an exaggerated case, but shows the bad effect of failure to carry the heat away from the cylinder bore rapidly. The top land of the piston must, of course, be given much more clearance than any other part. The next land requires less, and the least clearance can be given to the bottom of the skirt. The tapering necessarily increases rapidly as the top of the piston is approached. When the piston-pin is placed too near the rings, piston slaps are more frequent, for the clearance in the zone near the piston-pin bosses must be sufficient to take care of extreme heat conditions so that under ordinary running conditions this part of the piston has enough clearance to allow piston slaps. When the pin is placed farther from the head the clearance can be small enough to prevent slaps.

Some trouble has also been encountered due to fitting pins tightly in the piston. When a piston with a tight pin is heated, it expands and creeps out on the pin; when it contracts again, it hangs to the pin so that the piston has a greater diameter parallel to the pin and a smaller diameter at right angles to it. This condition makes seizing easier and slaps more pronounced. This creeping can be demonstrated readily by applying a blow-torch flame to the head of a piston fitted with a tight pin.

Excessive Oil Consumption

When too much oil is thrown into the cylinder bores, tight-fitting pistons and special rings will not completely overcome the trouble. A great many tests have been run which show this conclusively, demonstrating that:

(1) With no control on the oil being thrown into the cylinder, rings which seal the top and bottom edge of the groove reduced the oil consumption
(2) When the oil is properly controlled, the oil consumption is very low even with rings having an up-and-down clearance of 0.004 in.
(3) With the oil controlled and with hot water circulated through the engine, the volume of liquid in the oil-pan increased, indicating dilution with fuel which passed the piston and rings. This was independent of the kind of rings used

The engine was next run with a device arranged to heat the mixture to a temperature of about 160 deg. fahr. This was accomplished in such a way that the maximum

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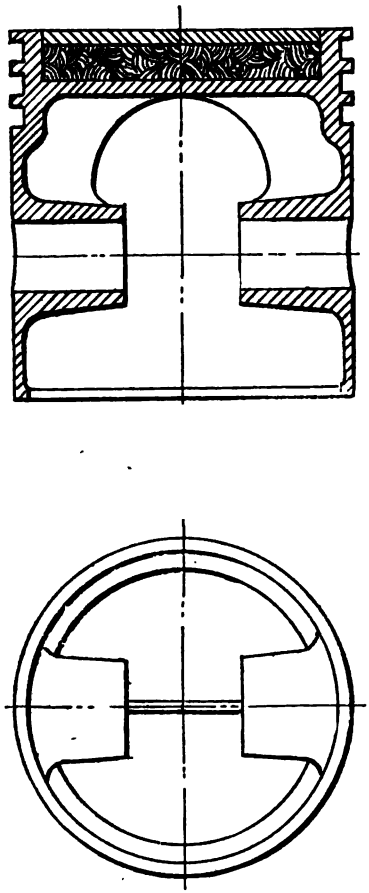

FIG. 11

amount of heat was applied when idling. The effect upon fuel vaporization was observed through a glass window and was clearly evident. The result was to diminish the amount of fuel in the oil-pan when idling, and the viscosity was not seriously affected.

Before the installation of the heating device a black deposit was found on spark-plugs taken from the cylinders of cars on road test even when the oil consumption was very low. After the installation, the spark-plugs remained clean under all conditions. It has been common

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practice for a number of years to put a quantity of kerosene in the crankcase oil, when running-in an engine to allow the bearing parts to seat more quickly. It is fair to expect that crankcase dilution has the same effect and that more rapid wear follows; hence the need for minimizing crankcase oil dilution with unburned fuel.

THE DISCUSSION

J. E. DIAMOND:—I noticed when in France and England, both during the war, and one time since, that manufacturers there were using much narrower rings both in iron and aluminum pistons than we use here. The French engineers attribute most of their success with alloy pistons, especially insofar as oil pumping is concerned, to the fact that they use narrow rings. I should judge most of those I saw to be but about half the width of our standard rings, with more of them being used; for example, in the 3¼-in. piston where we would use say three rings 3/16 in. thick, the French engineers specify four or five rings 3/32 in. thick and perhaps a little greater in depth than our own rings. I am more confident than ever that the aluminum-alloy piston is a sure thing. We may still have troubles with it but someone will solve these problems and soon we will find every car using alloy pistons. I think this piston will be very much along conventional lines yet embracing some special feature which will permit close fitting and at the same time allow the piston to yield when it would ordinarily seize.

H. M. CRANE:—The aluminum piston is of real value only where the question of heat conductivity is of great importance; that is in high-duty engines of large piston diameter. When it comes to motor-car engine work, the question of durability is of far greater importance than that of heat conductivity. Aluminum is not a good bearing metal. It will work in a cast-iron or a steel cylinder only as long as it is prevented from touching the wall. The first four-cylinder car in which we used aluminum pistons ran about 25,000 miles. We thought we had something fine; there was no perceptible wear on the cylinder walls and the pistons looked very good. We continued for another 15,000 miles and the car began to develop serious oil trouble. The car which had before been going 1500 to 2000 miles to a gallon began fouling spark-plugs and doing everything it should not have done. We found that the cylinders were tapered nearly ten thousandths from one end to the other. The pistons had

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finally reached a point where the upper land which had been cut way back began to touch and, being dry, as the upper land always is, it was the most beautiful lapping device you ever saw. We built twenty cars in Bayonne in 1912 with cast-iron pistons, rings and cylinders, and, to the best of my knowledge, a ring has never been changed in one of them since. I know of at least one that has run 80,000 miles; it has the same pistons and the same rings it started with. It is a better car on oil consumption now than it was at the end of the first 5000 miles. That is something that cannot be done with aluminum pistons from present knowledge.

I try to admire the French authorities for their efforts to control oil in the cylinders, but, from my experience, they do not know what real oil control in cylinders means. We had to redesign the aviation engine, as far as oiling is concerned, and in so doing we reduced the oil consumption one-half. In aviation engines we use narrow piston-rings; the engine comes rapidly down to a satisfactory bearing surface and we get tight pistons with a relatively small amount of running-in. Of course, the logical result is that the engine wears out more quickly, but we do not expect aviation engines to give the years of service that motor-car engines give. The motor car has to run about 10,000 miles before it is really in good running condition.

We were forced in production to make an aviation engine capable of wide-open running at the end of 4 hr. running-in, and without the help of any of the wear from dust, as with motor cars. In the case of our 300-hp engine, which had a 5½-in. bore, we attempted to do this with wide rings and the result was extremely unsatisfactory. We had to run it 8, 10 and 12 hr., and sometimes had to pull it down and replace rings. We changed to narrow rings and obviated the difficulty entirely. It is simply the usual engineering compromise. For motor-car work I am convinced that these so-called narrow rings are entirely wrong, being about half wide enough. I am running one of our big cars with wide rings, with about 0.008-in. clearance at the skirt, on a 4⅜-in. piston and with proper scraper rings. I brought the oil pressure up from 8 to 15 lb. without difficulty. There is practically no oil consumption whatever, in the sense that it causes any difficulty, as we are doing 1500 miles per gal. with a 568-cu. in. engine. I am convinced that the proper design of piston and ring is capable of giving satisfactory oil consumption, with very large piston clearances if you want them. Similarly with regard to piston-slap, which

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is largely caused by the piston being too short. On one of our earlier-model cars the pistons slapped badly with 0.005-in. clearance. We could not fit them much more closely than that and have them run. The result was that after 25,000 miles' running we had to replace them. In the next car we made we added 1 in. to the length of the piston, and quadrupled the length of the service of the car. I think that this shows almost conclusively that there are other considerations about piston design than that of what material to use in making them.

A. L. CLAYDEN:—What about the heat-treatment Mr. Pomeroy has given to alloys and the nature of the alloys he has treated? He stated, I believe, that he always gave pistons a normalizing treatment.

L. H. POMEROY:—The heat-treatment to which Mr. Clayden refers is that recommended by the firm which developed the Ricardo slipper piston. In pistons of that type there are two cylinders connected by webs at right angles to the line of cylinder bores and parallel to the cylinder axis. In sand castings it is found that certain contraction strains are produced so that, unless these are removed, it becomes a process of trial and error before the minimum running clearances can be obtained. It is found that by immersing these in oil at a temperature of 250 to 300 deg. cent. before finishing machining, these internal strains are removed so that it is possible to work to definite clearances. The aluminum alloy used in these pistons is a straight 12 per cent copper-aluminum alloy whose one recommendation compared to other alloys is the extreme satisfaction it has given.

MR. CRANE:—The pistons which I just referred to were made with 0.030-in. diametral clearance on the upper lands, which was plenty of clearance to start with. The trouble was caused by the aluminum gradually wearing at the center of the piston, and thus allowing the upper end of the piston to cock over.

As for the difference between wide and narrow rings, this appears to be largely a question of lubrication. I think that a really gas-tight piston-ring does not have a thoroughly-lubricated bearing surface; there is always a certain amount of metal contact. Probably it would not be tight on the very short length of bearing it has, unless it had almost a metal contact. The result is that the wider ring does not wear as fast as the narrower ring, even if the unit pressure is exactly the same. This, I think, is because the wide ring establishes a more complete oil-film than the narrower ring establishes. Fur-

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thermore, the wider ring rides over the irregularities in the cylinder to a far greater extent than the very narrow ring, which again raises the question of metal contact that brings the rings down quickly to a good bearing surface. After they have reached a good bearing surface, there is not the same difference in the rate of wear between the two. But in beginning to run a new engine with new rings there is no doubt that the narrow ring will run-in at least three times more quickly than the wide ring. In an engine running at high mean effective pressure, which means high cylinder pressure, the narrow ring is far safer because nowhere near as likely to leak at the start.

E. G. GUNN:—I am inclined to agree with Mr. Diamond that we can use narrower rings than we are now using. Rings ⅛-in. wide on a 3¼-in. piston seem to be satisfactory. I also agree with him that the aluminum piston has great merit. I think the wear that Mr. Crane mentions is not due entirely to aluminum. With cast-iron pistons cylinders are often found to be badly worn and other cylinders scarcely worn at all. We also find some engines in the same run of production that show twice as much wear in 10,000 miles as others, and it is rather difficult to determine exactly the cause of the extra wear. When running competitive tests, I have found that there is not much difference in cylinder wear between cast-iron and aluminum pistons. In some cases with aluminum pistons the cylinder wear has been considerably less. Of course, the oiling system and, what is more important, the quick heating of the mixture play very important parts.

In running a great many tests on the same engine I have found that unless the piston-pin is too near the top of the piston, adding as much as 2½ in. to the skirt of the piston, the length of the piston had no effect on piston-slap. The experiments were conducted very carefully and checked a number of times to avoid error. However, if the piston-pin is too close to the top of the piston, the effect is worse than it is with cast-iron pistons, on account of the high heat conductivity. This makes it necessary to have a greater clearance on the diameter at the piston pin.

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SUPERCHARGERS AND SUPERCHARGING ENGINES

By Major G E A Hallett,[1] U S A

If at great altitudes air is supplied to the carbureter of an engine at sea-level pressure, the power developed becomes approximately the same as when the engine is running at sea level. The low atmospheric pressure and density at great altitudes offer greatly reduced resistance to high airplane speeds; hence the same power that will drive a plane at a given speed at sea level will drive it much faster at great altitudes and with approximately the same consumption of fuel per horsepower-hour. Supercharging means forcing in a charge of greater volume than that normally drawn into the cylinders by the suction of the pistons. Superchargers usually take the form of a mechanical blower or pump and the various forms of supercharger are mentioned and commented upon. Questions regarding the best location for the carbureter in supercharged engines are then considered. Supercharging engines, in which compression in the crankcase or in the lower end of the cylinders is used to force an additional volume of air or mixture into the cylinders after completion of their normal suction stroke, are then reviewed, with discussion of their special features and comments upon present practice. In conclusion, the future of the supercharger is considered and the chief obstacles which must be overcome are mentioned.

The need for aeronautic engines that will deliver the same power at 20,000 or even 30,000 ft. altitude as they develop at sea level is very real and very great, in not only military but also in commercial aviation. Much success has already been attained with supercharging devices in this country and a certain amount of success in Europe. It must be admitted that there have been some failures also. It is the intention to outline past developments in supercharging in this paper and to point out the lines of attack which seem to be meeting with most success.

Supercharging, as the term is generally used, means forcing a charge of greater volume than that which is normally drawn into the cylinders by the suction of the pistons in conventional internal-combustion engines.

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When Supercharging Is Needed

At 20,000 ft. altitude the atmospheric pressure is roughly one-half that at sea level; hence about one-half the weight of charge is drawn into the engine and less than one-half the power is developed. At 25,000 ft. altitude less than 25 per cent of sea-level power is delivered. If at these altitudes air is supplied to the carbureter at sea-level pressure, or approximately 14.7 lb. per sq. in. absolute, the power developed by the engine becomes approximately the same as when running at sea level. The low atmospheric pressure and density at great altitudes offer greatly reduced resistance to high airplane speeds; hence the same power that will drive a plane at a speed of 120 m.p.h. at sea level will drive it much faster at 20,000 ft., and still faster at 30,000 ft. altitude, *and with approximately the same consumption of fuel per horsepower-hour.*

There is little to be gained by supercharging at sea level to increase the power of a given size engine, because the clearance volume must be made greater than normal to prevent preignition, with consequent decrease in the expansion ratio and comparatively poor fuel economy. The fact that the clearance volume is increased removes the possibility of the engine developing full power at great altitudes unless a supercharging capacity greater than anything heretofore considered feasible is available. Supercharging, therefore, is most useful in maintaining sea-level horsepower in engines ascending to or working at great altitudes.

Superchargers

Superchargers usually take the form of a mechanical blower or pump and, of course, require a driving gear of some kind. The types of blowers or compressors used to date include the reciprocating, Root displacement and centrifugal types. The reciprocating type was tried by the Royal Aircraft Factory early in the war, on an air-cooled R. A. F. engine, with practically no success. It seems that this type of blower was found to be comparatively heavy and also unsuitable, due to the pulsating pressure of the air delivered.

The Root type blower was tried by the Royal Aircraft Factory with little or no success. The trouble reported was "rough" running of the engine on account of the pressure pulsations in the air discharged by the blower, which tended to overcharge some cylinders and under-

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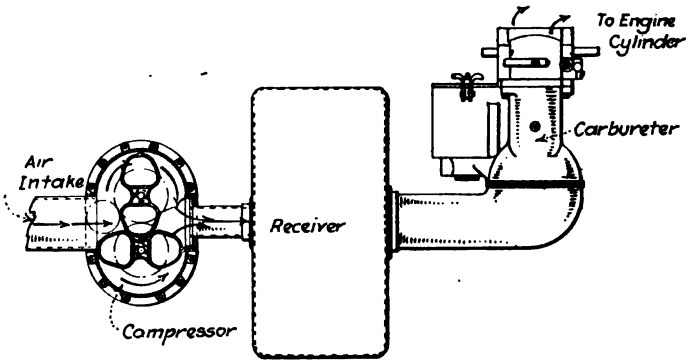

FIG. 1—IMPROVED ROOT TYPE BLOWER

charge others, thus causing uneven impulses. It is reported that mechanical troubles also developed with this type of blower. George W. Lewis, of the National Advisory Committee for Aeronautics, is working on an improved Root type blower, shown in Fig. 1. Here the pulsations in the air discharged are synchronized with the suction strokes of the engine. It will be interesting to note how this develops.

The centrifugal type of blower was used by Prof. Rateau, in France, early in the war. He employed the exhaust gases of the engine to drive a high-speed single-stage turbine direct-connected to the centrifugal blower, shown in Fig. 2. Some success was had from the start, but he encountered many mechanical troubles. It is claimed in recent reports that some fairly good results are being obtained by the French.

The Royal Aircraft Factory experimented in 1916 and 1917 with a gear-driven centrifugal blower, but as soon as an endeavor was made to run it at speeds that would step-up the pressure to the 5 or 6 lb. required, great difficulties were encountered on account of the inertia and momentum of the compressor rotor and the high-speed end of the gear-train, which resulted repeatedly in the breakage of the gears when the engine was accelerated or decelerated. To eliminate this trouble a friction clutch, designed to slip under excess torque, was tried, but only partial success was achieved, and the clutch itself gave considerable trouble. Light flexible vanes were then tried on the compressor impeller, but this expedient has not proved successful to date. Similar ex-

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periments were conducted by the A. E. F. in France but were concluded by the signing of the armistice.

The United States Air Service started work on the Rateau type of turbo-compressor soon after we entered the war. The work was done under the supervision of E. H. Sherbondy, who worked in conjunction with the Rateau-Bateau-Smoot Co. which handled the Rateau patents in this country, and designed a turbo-compressor which seemingly embodied many improvements over the Rateau type. Three of these machines were built and given ground tests on Liberty engines. The arrangement of the engine and the supercharger is shown in Fig. 3. Considerable trouble was encountered due to overheating of the exhaust-driven turbine, and even the use of a special heat-resisting metal in this part did not overcome the trouble. Soon after Mr. Sherbondy began work on the turbo-compressor, Dr. S. A. Moss, chief of the turbine research department of the General Electric Co., asked permission to carry on some work on the same general type. He built one turbo-compressor which was also a modification of the Rateau type but differed considerably from Mr. Sherbondy's machine. This device was tested on a Liberty engine at the summit of Pike's Peak and developed approximately sea-level horsepower there, at an altitude of 14,000 ft. It was capable of mak-

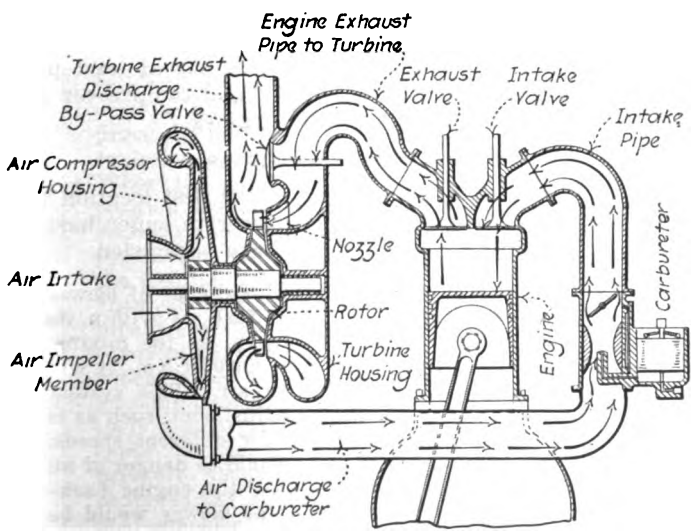

FIG. 2—RATEAU CENTRIFUGAL TYPE BLOWER

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ing the engine preignite at that height. The Moss supercharger, as first built, was of rather crude construction, and much mechanical trouble was encountered with all parts except the rotating element.

After the armistice was signed all work on the development of superchargers was stopped. When the engineering division of the Air Service took over McCook Field and started to plan peace-time development, the supercharger situation was carefully considered. It was decided that it was important to continue development work along this line. It then became necessary to decide whether work should be continued on both the Sherbondy and the Moss machines, and, if not, which one should be developed. It was noted that although Dr. Moss' machine was comparatively crude, it contained some inherent advantages over the Sherbondy type, and no way was seen to overcome the faults of the Sherbondy machine. Therefore, the latter was dropped and the General Electric Co. was given a contract to rebuild the old supercharger designed by Dr. Moss. The new device is now being tested in actual flight and giving very interesting results. Figures on the results obtained with the present Moss supercharger are naturally confidential. The indications are that the turbo-compressor is very durable and probably will outlast an aviation engine.

J. W. Smith, a designer and builder of air-cooled radial engines, located in Philadelphia, is known to have designed a turbo-compressor for this type of engine. The B. F. Sturtevant Co. at Boston, Mass., has at least partially developed a belt-driven centrifugal compressor for supercharging one of its aircraft engines.

Carbureter Locations

There is still some question as to the best location for the carbureter in relation to the blower in supercharged engines. Apparently all positions have been tried.

(1) It is possible to use the centrifugal type of blower as a carbureter by placing a fuel jet within its housing and allowing the rotor to do the mixing. As the rotor usually runs over 20,000 r.p.m., it will certainly mix liquid fuel with air. This system would require a manual fuel adjustment, such as is used with the Gnome engine, for different speeds. With this arrangement there would be danger of an explosion in the blower in case the engine backfired, because the mixture in the blower would be under pressure higher than atmospheric

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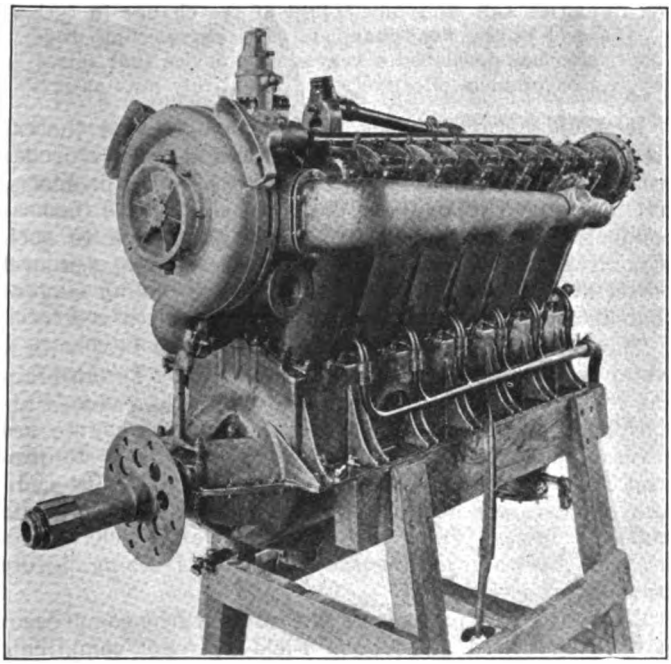

FIG. 3—SHERBONDY SUPERCHARGER MOUNTED ON ENGINE

(2) The carbureter can be placed on the suction side of the blower. In this case the evaporation of the fuel will assist in cooling the charge during compression and the action of the compressor will improve the mixing of the fuel, but the danger from explosion remains to be overcome

(3) When the carbureter is placed in the "normal" position and air is forced through it, it becomes necessary to "balance" the float-chamber with supercharger pressure. This somewhat complicates the feeding of fuel. Pressure gas-feed systems are "banned" in military planes and in any case with a pressure system the tanks would have to be made comparatively heavy to withstand the pressure which would be used at great altitudes. Where gasoline pumps are used it is necessary to regulate their discharge pressure as the plane ascends, because the fuel must reach the float-chamber at a pressure about 2½ lb. higher than that at the supercharger outlet. If the difference in fuel and float-chamber pressures is not kept in constant relation, the quality of the mixture fed to the

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engine will vary on account of the change in fuel level in the float-chamber. The engineering division has developed a very simple device that solves this problem effectively and is entirely automatic

It would naturally seem at first thought that the extremely low temperatures always found at great altitudes would make possible the easy solution of cooling problems, but in reality the low density of the air reduces its heat conductivity and capacity for heat absorption to such a point that a supercharged engine developing sea-level power at 20,000 ft. requires a little *more cooling surface* than it does when developing normal power at sea level.

The Liberty engine and many others run best with a water temperature of about 170 deg. fahr. To maintain the cooling water at this temperature in the reduced atmospheric pressure at 25,000 ft. it is necessary to use several pounds of air pressure in the radiator to prevent the water from boiling away. Very effective radiator shutters are needed when the engine is throttled to make a descent from altitudes of over 20,000 ft. to prevent the water in the radiator from freezing before warmer air is reached.

Contrary to expectations, the Moss turbo-compressor now being tested at McCook Field does not complicate the pilot's controls. On a normal engine the pilot handles the throttle and the altitude carbureter control which thins down the mixture as he ascends. With the turbo-compressor the altitude control becomes unnecessary up to the altitude at which the engine can no longer deliver sea-level power but is used, as with a normal engine, if the plane is driven higher.

With the Moss turbo-compressor, when flying at low altitudes, the exhaust pressure is allowed to "waste" through manually operated "gates" in the exhaust pipes. As the plane ascends the pilot closes these gates a little at a time and after he reaches a great altitude he can speed and retard the plane by the use of these gates. He uses the throttle only in case he wants to descend rapidly, when he closes it. In our test flights we have provided the pilot with a sealed altimeter connected only to the supercharger pressure, so that it shows to what altitude this pressure corresponds. When at great altitude the pilot closes the exhaust gates until the pressure in the carbureters causes the altimeter to show sea-level pressure. This makes it unnecessary for him to do any calculating. If he makes the gage read lower than sea

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level, the engine will preignite. We have already been able to obtain sea-level pressure in the carbureters at well over 20,000 ft. The exact height cannot be mentioned at present.

With a normal engine the falling off in power as the plane ascends does not cause as much of a drop in propeller speed as might be expected, because of the reduction in density of the air in which the propeller is working. Our best engines do not lose over 75 r.p.m. at 20,000 ft. When an engine is supercharged so that the power remains constant as the plane ascends, the propeller tends to "race" at great altitudes. Therefore it is necessary either to use a variable-pitch propeller or to put on one that holds the engine speed down too low for best performance on the ground but also does not allow the engine to race too much at great altitude. In our present tests we are using an oversize propeller and getting surprisingly good results, but we also have

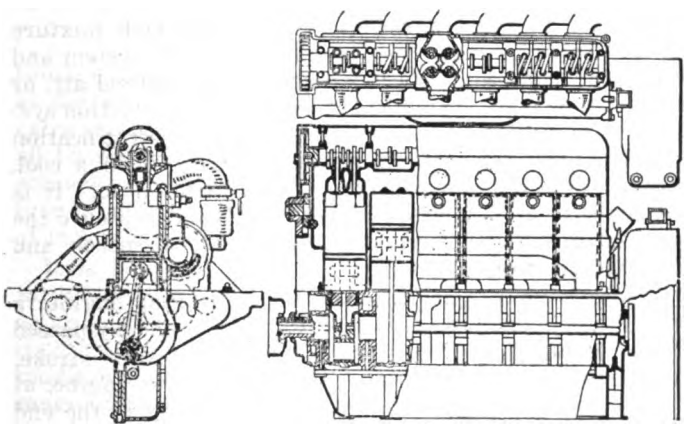

FIG. 4—KESSLER SUPERCHARGING ENGINE

variable-pitch propellers about ready for test and should get much better performance with them.

SUPERCHARGING ENGINES

As generally used, the term "supercharging engines" refers to internal-combustion engines in which compression in the crankcase or in the lower end of the cylinders is used to force an additional volume of air or mixture into the working cylinders *after completion of their normal suction stroke.* Early in the war the Army and

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the Navy each placed an order with the Kessler Motor Co., Detroit, Mich., for several experimental supercharging engines. This type of engine, shown in Fig. 4, supercharged each cylinder by the use of crankcase pressure, as is possible in four-cycle engines. Experiments were made using both air and mixture in the crankcase. Considerable difficulty was encountered in both the design and construction of the engine and so far as the engineering division has learned, no complete tests have been run; and in the small amount of testing that has been done no very large increase in power or brake mean effective pressure has been shown officially. It is believed that the frictional losses will prove to be very high in this type of engine and that the supercharging will be comparatively limited. A similar engine which was tested in this country did show very high frictional loss, due partly to the work of operating the valves which controlled the crankcase air.

An interesting problem in this type of engine when using air in the crankcase is whether a rich mixture should be fed through the regular induction system and an effort made to dilute it with the supercharged air, or a normal mixture should be fed through the induction system and an attempt made to obtain perfect stratification and thus let the supercharged air merely form a cool, elastic and expanding cushion on the piston-head. It is feared that in either case it will be difficult to secure the desired results through a large range of speeds and throttle positions.

There is an English make of supercharging engine in which air is compressed under the piston and by-passed through cylinder ports at the bottom of every stroke, (see Fig. 5) supercharging, as in the Kessler engine, at the end of the suction stroke and scavenging at the end of the exhaust stroke. It is claimed by the inventor that this scavenging makes possible the use of higher compression and greatly improves the fuel economy and brake mean effective pressure. It is believed that this engine will give rather limited supercharging and it may prove difficult to control the mixing or stratification of the air and mixture at some speeds.

In an English rotary air-cooled engine the pistons travel out to the cylinder-heads on the scavenging stroke and the beginning of the suction stroke and continue an extra distance inward at the end of the suction stroke, thus taking in a larger charge than that of a conven-

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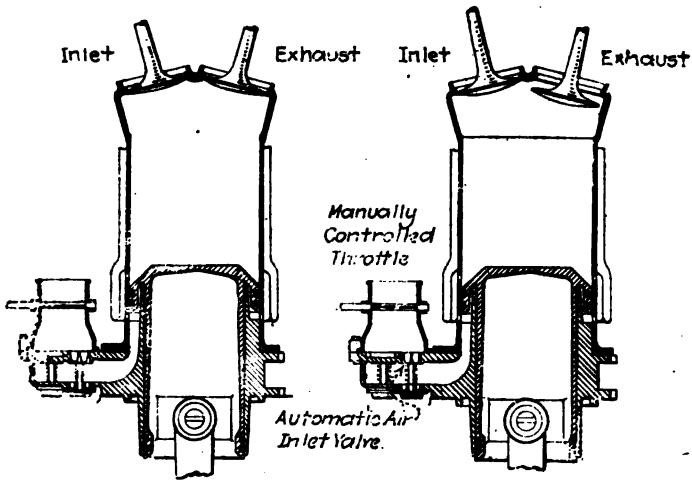

FIG. 5—ENGLISH SUPERCHARGING ENGINE

tional engine. The piston reaches only a normal position at the end of the compression stroke and continues an extra distance inward at the end of the suction stroke; all by means of an eccentric crankpin bearing which is rotated on the crankpin by gears of suitable ratio. This type of engine must certainly give a very limited amount of supercharging.

It is believed that supercharging engines will necessarily give a rather limited amount of supercharging. It is also believed that considerable difficulty will be encountered in obtaining the desired stratification in mixing conditions in the combustion chamber through any wide range of throttle positions. Also, some mechanical friction is added in this type of engine and it must be borne in mind that friction is particularly undesirable at great altitudes because it remains nearly constant from the ground up to great altitudes while the power falls off rapidly; therefore, the mechanical efficiency of the engine becomes very low.

The Root type of blower might be interesting for supercharging purposes if the troubles caused by the pulsating nature of its discharge could be eliminated. It is hoped that Mr. Lewis' efforts along this line will meet with success.

It is already frequent practice to build aviation engines with compression so high that the throttle cannot be

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fully opened on the ground without injury to the engine. In this way, perhaps, the same power is obtained at 5000 ft. as can be obtained on the ground. It has been suggested that this idea be carried further and that an "oversize" engine be built with much higher compression so that the throttle cannot be opened fully until a considerable altitude, such as 10,000 or 15,000 ft., is reached. It has been stated that such an engine could be made lighter, in proportion to the cylinder sizes, than a conventional engine, on account of the fact that the throttle would never be opened near the ground, but it is believed that when this idea is investigated, it will be found that it is the inertia forces quite as much as the explosion forces that determine the necessary strength in most high-speed airplane engine parts and that therefore such an engine could not be built light enough to make it practical. In any case, it is doubtful whether this would give a really good solution for flying at 25,000 or 30,000 ft.

It is possible that centrifugal compressors can be operated satisfactorily by gears or by a belt drive. It is known that some designers are working on both of these problems.

The turbo-compressor in which an exhaust-driven turbine is used for driving the centrifugal compressor, seems to present one fairly good way of accomplishing the desired purpose. The turbo-compressor itself is very simple, as there is only one moving part, namely the rotating element consisting of the turbine wheel and compression impeller. The bearings of this rotating element do not seem to wear noticeably and the device imposes very little drag on the engine when not being used for supercharging. The turbo-compressor is also an effective exhaust muffler.

The Future of the Supercharger

It is believed that when the present type of turbo-compressor now being tested by the engineering division has been more fully developed, it can be built into an engine in a form which will add less weight and less head-resistance than the present machine, and naturally when we know exactly what additional cooling surface is required at a given height, it will not be difficult to build this cooling surface into the airplane in such a form that very little weight and head-resistance will be added.

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The uses of the supercharger for military service can be divided into, first, for airplanes in which it is desired to reach extreme altitude; second, for airplanes in which it is desired to increase the rate of climb and horizontal speed and therefore maneuverability at altitudes where it is intended to fight; and, third, for airplanes which carry large loads, such as bombers, which normally are handicapped by having a very low ceiling and whose entire usefulness would, if larger engines were installed to pull them to a higher ceiling, be lost on account of the larger amount of fuel and other material that would have to be carried, thus decreasing their radii of action.

In the first case it is believed that a special supercharger can be built that will make feasible much greater altitudes than any that have been attained with the present General Electric turbo-compressor; and it is considered essential that we have airplanes capable of reaching very great heights. In the second case, it is pointed out that military machines not fitted with supercharging engines, when fighting at an altitude of 20,000 ft. or more, are so near their ceiling that their rates of climb, speed and maneuverability are comparatively poor, but the use of a supercharger seems to overcome this difficulty easily. When a pilot climbs with a normal engine to 20,000 ft. and then levels off in horizontal flight, the engine and propeller speed up perhaps 100 r.p.m. This, of course, enables the engine to develop slightly more power. In the case of a supercharged engine, especially with the turbo-compressor type of supercharger, as the engine speeds up in horizontal flight, the temperature of the exhaust and the power available from the exhaust increase, thus building up the supercharging pressure and giving considerably greater increased power than with a normal engine.

The use of superchargers in commercial airplanes of the future is assured because superchargers will make possible far *more miles per hour* and *more miles per gallon* with a given engine and airplane, and speed is the main advantage of air over other kinds of transportation. It is thought by many qualified judges that by flying at a sufficient height with a supercharged engine and a suitably designed airplane, a speed of 200 m.p.h. can be maintained.

In the heavy-load-carrying type of plane which must necessarily cross mountains or perhaps fly above storms and clouds, the necessary height can be reached with

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smaller, cheaper and more economical engines if they are fitted with superchargers. It is obvious that in really long cross-country flights or trans-continental flights, with mail or passengers, the logical course is to fly at 25,000 or 30,000 ft. altitude where the resistance to speed is low and great speed can therefore be attained provided the engine can deliver high power economically, which it can do if equipped with a supercharger.

As a graphic illustration of the advantage of a supercharged engine, it is pointed out that at 25,000 ft. altitude a supercharged 250-hp. engine will deliver as much power as a 1000-hp. engine without a supercharger; and of course the former will weigh many hundred pounds less, its fuel and tankage will weigh very much less, the first cost will be much lower and the structure of the airplane can be made much lighter.

THE DISCUSSION

T. S. KEMBLE:—Major Hallett's paper should be of greater than passing interest, especially to those who have had any part in aeronautic development. The opening sentence of the paper tends to convey an impression which was perhaps not intended. I mean the impression that the powerplants of commercial airplanes will be called upon to deliver full sea-level power habitually at very great altitudes. I would not assent to any assertion that data are lacking for the design of light engines capable of delivering high sea-level power for long periods. Another factor however militates strongly against the habitual use of full sea-level power. Our present-day airplanes have maximum power equipment sufficient to fly at speeds too high for greatest fuel-per-mile economy. This is necessary and desirable in order that partial decrease of power from any cause may not involve a too serious risk. When the airplane is brought to a proper commercial basis it will continue to carry excess power, but will fly at a speed approaching that which is most efficient. It will use maximum power only in climbing and in emergencies. It is fortunate that this condition obtains. It means that however sturdy the airplane engine becomes, the conditions of service will give longer life and require less attention than would be possible otherwise.

We have a further advantage in that superchargers will ordinarily be called upon to make up only part of the difference between sea-level and great-altitude air

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density and cooling, and propeller problems are rendered less difficult. An added advantage in connection with superchargers lies in the simple means which they offer for furnishing the pilot and passengers with air at such temperature and density as to obviate the discomfort ordinarily attendant upon great-altitude flying.

MAJOR G. E. A. HALLETT:—Mr. Kemble's points are good. I heartily agree with him as to the necessity for running airplane engines at far below their maximum power output for the sake of durability, especially for commercial use. A supercharged engine, supercharging to bring it up to 0.8 of its sea-level power at an altitude of 20,000 ft., would correspond in durability to an unsupercharged engine running at 0.8 of its rated sea-level power, or approximately wide-open throttle, at 5000 ft. but would make much greater speed due to the lowered density of the air at the great altitude.

As to the need for full speed in commercial aviation, there are times when this is the most economical speed. For example, consider the extreme case of an airplane capable of making 100 m.p.h. flying while throttled down to an air speed of 70 m.p.h. and flying against a 70-mile head wind. The result would be that the airplane would be standing still and the fuel necessary to drive it at an air speed of 70 m.p.h. is totally wasted as far as getting anywhere is concerned, while if the throttle is opened so that the airplane makes its maximum air speed of 100 m.p.h., the fuel that is burned is driving the airplane toward its destination at the rate of 30 m.p.h. Hence, a greater economy is effected than if the engine is run partly throttled down and, as Mr. Kemble points out, a supercharger, supercharging to only 0.8 of sea-level power at 20,000 ft., for example, is much easier to accomplish and presents much less of a propeller problem than complete restoration of power at this or greater altitudes.

Mr. Kemble is entirely correct in his statement that the supercharger provides means of keeping the pilots and passengers comfortable with air of the proper temperature and density. The engineering division has for some time planned to arrange an airplane in this manner for Major Schroeder's use in his extreme great-altitude experiments and for use in proposed high-speed cross-country flights at considerable altitude.

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DILUTION OF ENGINE LUBRICANTS BY FUEL

By Gustave A Kramer[1]

Engine lubrication troubles resulting from the dilution of the lubricating oil in engine crankcases appear with increasing frequency, particularly where economy demands the use of cheap grades of fuel. Unless a lubricant not miscible with present engine fuels can be produced, lubricants will steadily decrease in viscosity whenever fuel finds its way into them. The most satisfactory remedy is to prevent dilution of the oil. To prevent absorption of the fuel by the oil is a problem of engine design. In experiments made by the Bureau of Standards the absorption of fuel vapors at average engine temperatures was found to be negligible; further experiments and oil tests showed no indication of dilution due to cracking, with representative refiners' products from typical crude oils available in this country. Information was necessary relative to the effect on the viscosity of lubricating oils of their dilution with varying percentages of fuels; the maximum temperature to which they can be raised without serious deterioration when exposed to the air and to their own vapor, and the maximum temperatures to which they must be heated to remove the necessary proportion of the fuels they contain. A series of experiments made to determine the effects of fuel admixture on oil viscosity is therefore next considered and this statement is supplemented by additional data and discussion relative to distillation methods for removing the fuel from the oil. Several further experiments were carried out to indicate possible improvements through simple changes in distillation methods, relative to time of heating and area of free surface exposed. The ultimate solution of the problem is believed to lie along the line of new departures in engine design that will prevent the accumulation of liquid fuel in the cylinders and in the lubricating system. In an appendix suggestions are made advocating the use on existing engines of some self-contained device for restoring the viscosity of lubricating oils, with some details regarding the features such a device should embody.

Parallel with the decline in the volatility of commercial gasoline, complaints have appeared with increasing fre-

[1]Chemical engineer, Bureau of Standards, Washington.

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quency of engine lubrication troubles resulting from the dilution of the lubricating oil in engine crankcases. The trouble is particularly pronounced in tractor engines where economy demands the use of the cheapest possible grade of fuel.

How much of the trouble reported is really caused by dilution of the lubricant would be difficult to trace. Nevertheless it must be admitted that the problem does exist and that it is becoming more serious with the steady decrease in volatility of internal-combustion engine fuel. Inasmuch as this decrease is due to an increased demand, no relief through an increase in volatility of the fuel is in sight. The situation must then be squarely faced by the engineers of the country and attacked from every direction that promises a solution of the problem.

The most satisfactory method of handling investigations of this kind is usually that of elimination; the finding of answers to the simple questions which form a part of the more complex problem. The Bureau of Standards is attempting to throw light on a few phases of the subject. The work described was done as a part of the general investigation of lubricants and lubrication now under way and was naturally confined to the influence that the properties of the available lubricating oils have on the phenomena of crankcase dilution. The properties of the oils must to a certain extent be regarded as rigidly fixed, the oils being products of refining from available crude oils as are also the fuels under consideration. There exists a wide range of viscosities from which to choose, but the possible range for a given type of engine is comparatively narrow and still narrower for any individual engine. From our present knowledge, there is little hope of finding an oil whose viscosity will not be affected by the admixture of gasoline and kerosene. Even castor-oil, the only commercially available lubricant that at ordinary temperatures does not mix with gasoline and kerosene in all proportions, loses this property at engine temperatures. Experiments made by the Bureau of Standards on a commercial sample have shown that it dissolves an equal volume of kerosene at 35 deg. cent. (95 deg. fahr.), and an equal volume of gasoline at 24 deg. cent. (75 deg. fahr.). In fact, above 43 deg. cent. (110 deg. fahr.), either gasoline or kerosene will dissolve in castor-oil in any proportion, and the reduction in the viscosity of castor-oil is probably no less for the same dilution

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than that of an equally viscous petroleum oil. (See Fig. 2). Since an oil is usually above 40 deg. cent. (104 deg. fahr.) the major portion of the time that an engine is in operation, it is evident that castor-oil offers no solution of the difficulty. Unless some unforeseen discovery should enable us to produce economically a lubricant not miscible with our present engine fuels, we must expect to lubricate our engines with oils which steadily decrease in viscosity whenever a part of the fuel can find its way into the oil. To substitute oils of higher viscosities so that even considerable dilution could be permitted would only mean postponing and not preventing the trouble.

Two Possible Solutions of the Problem

This being the case, two logical ways remain for overcoming the difficulties. The first and most satisfactory is to prevent dilution of the oil. The second is to separate the fuel from the oil, thereby restoring the oil to its original viscosity as nearly as is possible.

To prevent absorption of the fuel by the oil is a problem of engine design. Better atomization and vaporization would undoubtedly aid. The cross-head-type engine, whose cylinders are relieved of all side-pressure and therefore require only sparing lubrication, might afford a step in the right direction. But the elaboration of these possibilities is beyond the scope of this paper.

When considering oil dilution by fuel, it should be remembered that, during the suction and compression strokes, the lubricant on the cylinder-walls is in contact with the air-fuel mixture. This oil may absorb part of the fuel and then drip from the cylinder-walls into the crankcase. Moreover, even the best fitting pistons and rings allow some of the cylinder charge to leak into the crankcase during compression.

Experiments were therefore undertaken to determine to what extent the absorption of fuel vapors can occur at average engine temperatures. A simple apparatus was set up and arranged so that a measured volume of a uniform gasoline-air mixture could be bubbled through the oil under examination. A steam bath permitted temperature control of both the oil and the gasoline-air mixture. The amount of vapors absorbed during a given time was determined by the increase in the weight of the oil. The results show that there is a limit to the amount of gasoline vapors absorbed under these condi-

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tions. That this limit is rather definite was shown by the fact that after a certain gain in weight had been observed and the oil replaced in the system, the drawing of a second equal volume of the gasoline-air mixture through the oil produced no increase in weight. The use of a considerably richer mixture resulted, as would be expected, in a greater increase in weight. Repeating the first experiment with oil to which a quantity of gasoline had been added, a decrease in oil weight resulted such that at the end of this experiment it was approximately the same as at the completion of the first experiment. These experiments thus indicate that a point of equilibrium is soon reached, at which the gasoline evaporates from the oil at the same rate as that at which the oil absorbs it. The amount of gasoline in the oil when this point is reached is not large, ranging from 0.4 to 2 per cent with different oils and various gasoline-air ratios. It should be noted in connection with this experiment that a high grade of gasoline was used throughout so that it entirely evaporated in the air-current before reaching the oil.

Although the method just described was an approximation of the conditions to which a lubricant is subjected in an engine as regards gasoline-air mixtures, it was thought that apparatus based on a different principle, that of partial vapor-pressures, would be more satisfactory for further work. Such apparatus has been built and sufficient work has been done to indicate that the point of equilibrium already mentioned, while varying with different oils, is in no case greater than the maximum given. From present indications it must consequently be concluded that this source of dilution, the absorption of fuel vapors at engine temperatures, is negligible.

Cracking Process in Engines

There is another method by which the viscosity of oils may be reduced that is the topic of much discussion at present. The assertion is frequently made that there is no need of explaining the observed reduction in viscosity of lubricants by their dilution with unburned fuel, because a process similar to that used in the manufacture of gasoline from the heavier hydrocarbons, called "cracking" by refiners, is continuously in progress on the overheated metallic surfaces of the engine. I have

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never heard any oil-refiner make or sustain this statement, but the opinion of the Bureau of Standards on this subject has been sought so frequently that a few remarks seem warranted.

The results from a series of oil tests made by the Bureau of Standards, in an aircraft engine operating continuously for periods of from 5 to 11 hr. at nearly full load, showed no indication of dilution due to cracking with the oils used, these being representative of the refiners' products from the typical crudes available in this country. In these tests the viscosities of all the oils used increased steadily during the runs. The amount of light fractions, those distilling below 232 deg. cent. (450 deg. fahr.), found in the crankcase oil, was at no time during the test greater than 1.5 per cent by volume; and an examination of these light fractions showed nearly the same percentage of unsaturated compounds as the original fuel. Had there been any dilution due to cracking, this would have been indicated by the presence of a larger proportion of unsaturated compounds.

It is not claimed here that some destructive distillation of the oil does not occur in engines. It is probable that whenever a few drops of oil come into contact with an engine part hot enough to cause cracking, the light products formed are spontaneously evaporated by the heat of the part. True cracking of hydrocarbons occurs, to a considerable extent, only at a much higher temperature than is generally imagined and seldom below 300 deg. cent. (572 deg. fahr.). Tests on an airplane engine were selected because of the high temperatures to which the oils are subjected in this type. The temperatures in tractor engines are not much lower, but in neither type, if well designed, do enough parts ever attain sufficiently nigh temperatures to give any considerable amount of cracked products.

To prove or disprove conclusively whether spontaneous decomposition of an oil can occur at the temperatures prevailing in internal-combustion engines, requires the determination of the cracking temperature of that oil. The Bureau of Standards has devised a simple apparatus for this purpose, although this is still in process of development. Until such apparatus is proved satisfactory, or until further information is obtained, judgment as to cracking of oils in engines must rest on the fact that no dilution due to decomposition has been found to any considerable extent in used lubricating oils.

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Possibility of Immediate Relief

Even if an engine should be developed within a short time that conformed to the requirements necessary to prevent oil dilution, relief would reach the owner only as the engines in use were replaced by the new design, and this would be a matter of several years. For the intervening period, the second means suggested for preventing lubrication trouble from fuel dilution may be found applicable. This is to prevent failure of lubrication by removing a sufficient portion of the fuel which has entered into the oil. The simplest practical procedure for this would appear to be some process of distillation, carried on at temperatures high enough to evaporate the major portion of the absorbed fuel, yet

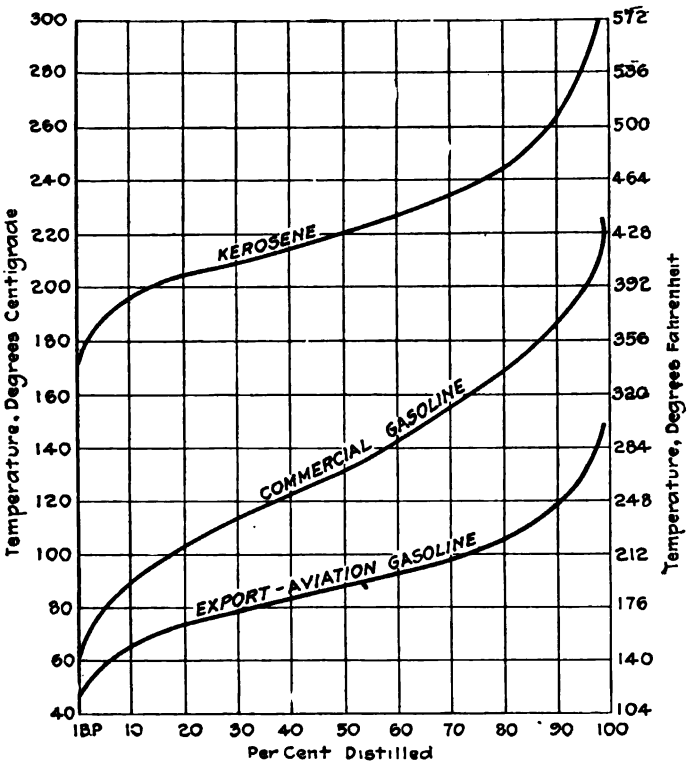

Fig. 1—Distillation Curves of Fuels

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below those at which oxidation of the oil would occur to a serious extent.

Before attempting to apply the great fund of available information on distillation methods to the solution of this problem, data are necessary on three questions relative to lubricating oils:

(1) What is the effect on the viscosity of lubricating oils of their dilution with varying percentages of fuels? The allowable percentage of fuel dilution can be determined when the permissible viscosity-range of the lubricant for the engine is known

(2) What is the maximum temperature to which lubricating oils can be raised without serious deterioration loss or danger when: (*a*) exposed to the air and (*b*) exposed to their own vapor? No definite answer can be given to this question at present although, as has been stated, it is not probable that serious cracking of properly refined lubricants will occur at temperatures lower than 300 deg. cent. (572 deg. fahr.). Oxidation will occur even at lower temperatures, but its extent will depend upon the exposed surface, the amount of air and the time of heating

(3) What are the maximum temperatures to which oils must be heated to remove the necessary proportion of the fuels which they contain? The maximum temperature which it may be necessary to reach to remove a given fuel can be judged from the upper distillation temperatures of the fuel, but experiments described later indicate that much lower temperatures than this will suffice

Effects of Fuel Admixture on Viscosity

A series of experiments to determine the effect of dilution by fuels on the viscosities of lubricants has been carried out with four oils of different origin, representative of the principal crude oils of the country and having viscosities usually encountered in lubricants for internal-combustion engines. These oils were diluted with two fuels in varying percentages. The fuels used were:

(1) An average grade of fuel gasoline
(2) A sample of commercial kerosene

Distillation curves of these fuels are given in Fig. 1, as determined by the method for distillation of gasoline developed by the Bureau of Mines. The viscosity of each oil was first determined undiluted and then when

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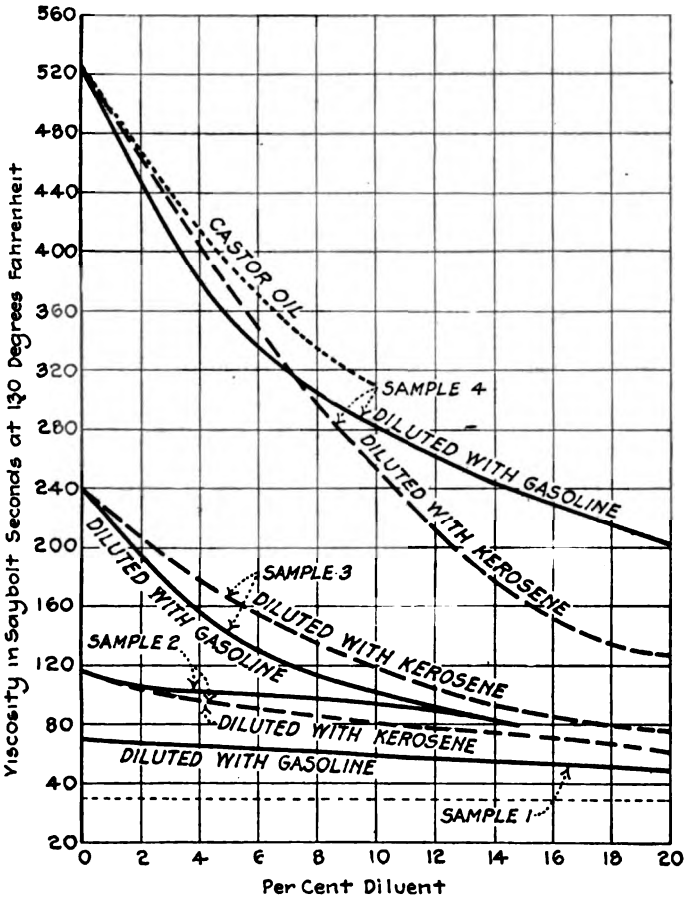

FIG. 2—CHANGE IN VISCOSITY OF LUBRICATING OILS RESULTING FROM DILUTION

diluted with different percentages by volume of the two fuels.

The results of this series of experiments are given in Figs. 2 and 3. Fig. 2 shows the change in viscosity of the four different oils, expressed in Saybolt-seconds, resulting from their dilution with varying quantities up to 20 per cent by volume of commercial gasoline and kerosene. The results of a few experiments with aviation gasoline are similar in their general characteristics to those of commercial gasoline and are omitted to avoid

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confusion. The values of the viscosities of the gasoline and kerosene used as diluents are about 29 and 31 Saybolt-seconds, respectively.

For the same dilution, the decrease in viscosity of the more viscous oils is much greater than that of the lighter ones. Where nearly the same viscosity-range is permissible with a heavy and a light oil, a higher percentage of

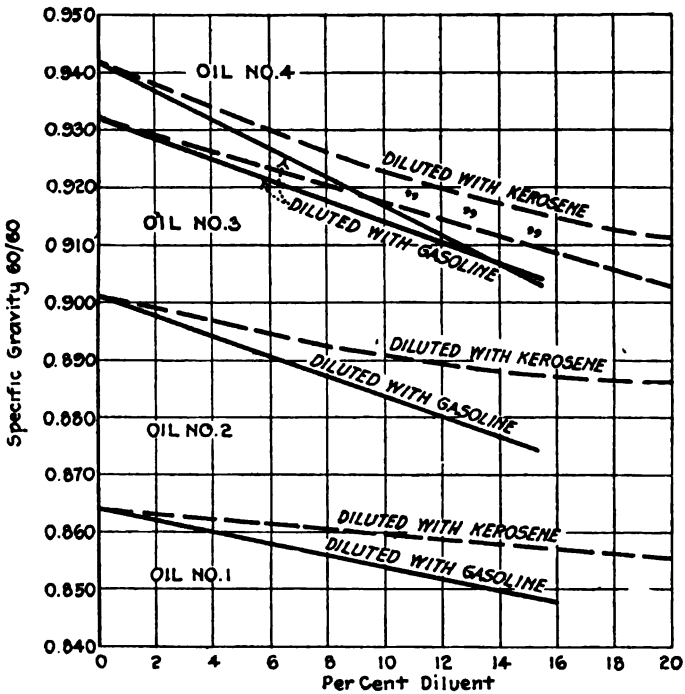

FIG. 3—CHANGE IN SPECIFIC GRAVITY OF LUBRICATING OILS RESULTING FROM DILUTION

dilution would be permitted with the lighter oil. Fig. 3 shows the change in specific gravity of the same oils when diluted with different percentages of fuel gasoline and kerosene.

Data such as those given would show what percentage of dilution could be permitted when the viscosities required for any given service were known. The numerical value of these viscosities and the permissible range of their variation must be determined for individual

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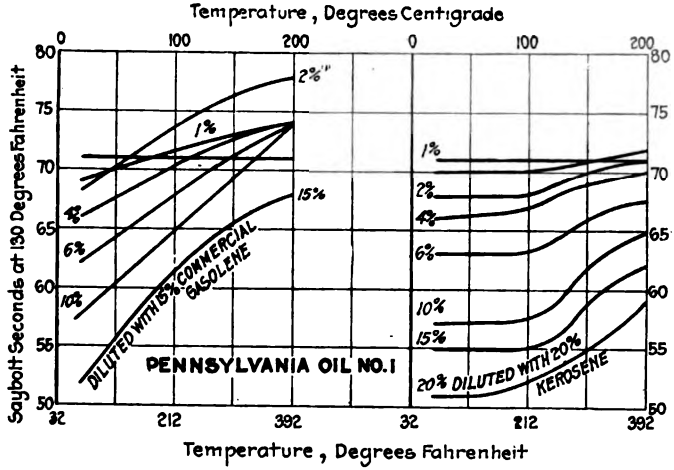

FIG. 4—CHANGE IN THE VISCOSITY OF A LUBRICATING OIL-FUEL MIXTURE RESULTING FROM DILUTION

cases. The data given are, however, suggestive of what can be expected with existing oils.

SEPARATION BY DISTILLATION

When considering distillation methods for the removal of the fuel from the oil the simplest method is the heating of the liquid to be treated in an open dish exposed

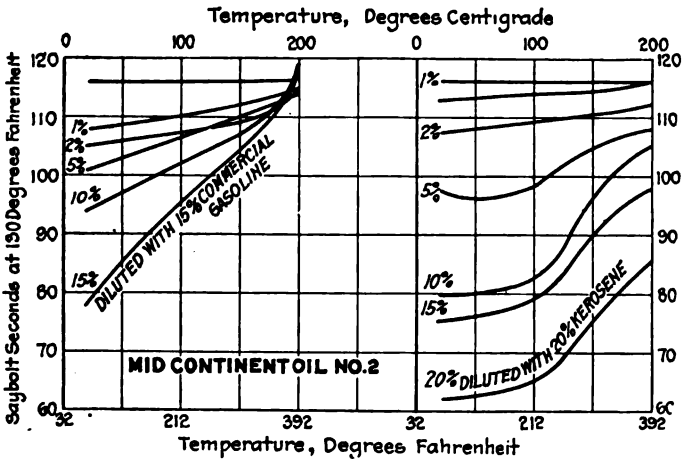

FIG. 5—CHANGE IN THE VISCOSITY OF A MIXTURE OF LUBRICATING OILS AND FUEL CAUSED BY DILUTION

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to the air. It was felt that data showing the results of the use of this very simple process, when applied to oil diluted with fuel, would serve to indicate the degree of refinement necessary in distillation methods to be used for the removal of the fuel from oil, and the maximum temperatures which it would be necessary to reach.

With this in view, the samples of the four different oils previously diluted with varying percentages of fuels were used. In carrying out the experiments each sample of oil was heated to 100 deg. cent. (212 deg. fahr.), held at this temperature for 5 min. and then allowed to cool. Its viscosity and specific gravity were then meas-

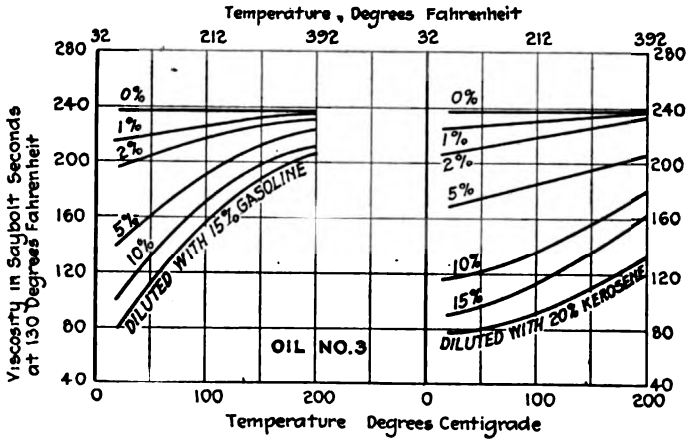

FIG. 6—HOW DILUTION AFFECTED THE VISCOSITY OF A MIXTURE OF FUEL AND LUBRICATING OIL

ured. The same sample was then heated to 150 deg. cent. (302 deg. fahr.), held there for 5 min. and again allowed to cool. Its viscosity and specific gravity were again measured. Finally this operation was repeated with the same sample held at a temperature of 200 deg. cent. (392 deg. fahr.) for 5 min. Figs. 4 to 11 show the results of these experiments. In Figs. 4 to 7 the change in viscosity of the oil-fuel mixtures after heating successively to 100 deg. cent. (212 deg. fahr.), 150 deg. cent. (302 deg. fahr.), and 200 deg. cent. (392 deg. fahr.), is given.

After heating to 150 deg. cent. (302 deg. fahr.), the oils diluted with commercial gasoline were restored to what would seem to be a safe viscosity, considering the original value for the oil. The results with aviation

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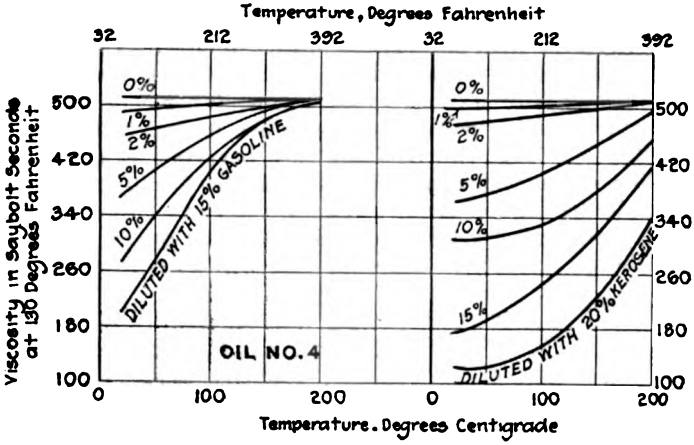

FIG. 7—ANOTHER EXAMPLE OF HOW DILUTING A LUBRICATING OIL WITH KEROSENE AND GASOLINE CHANGED THE VISCOSITY OF THE OIL

gasoline which are not shown on the curves are very similar. Practically all the gasoline had been removed at 150 deg. cent. (302 deg. fahr.), and the greater proportion at 100 deg. cent. (212 deg. fahr.). With kerosene the results are not so encouraging. In the attempt to remove the kerosene, heating to 100 deg. cent. (212 deg. fahr.) had practically no effect in the case of the two lighter oils and with the heavier oils much less effect than the heating to 150 deg. cent. (302 deg. fahr.). An examination of the distillation curves of the fuels will assist in explaining this result by showing the effect

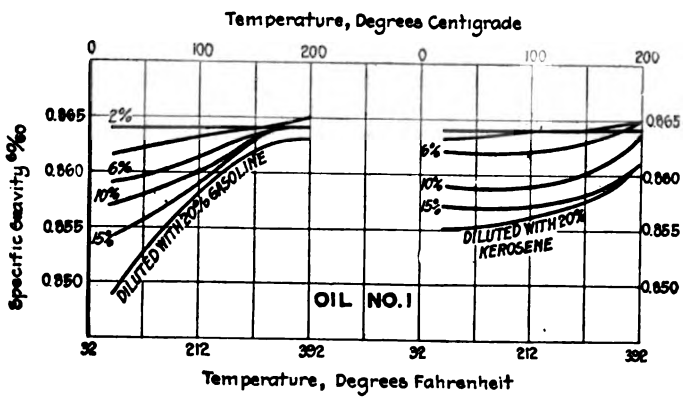

FIG. 8—CHANGE IN THE SPECIFIC GRAVITY OF A LUBRICATING OIL FOLLOWING ITS DILUTION WITH VARYING PERCENTAGES OF FUEL

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of the volatility of a fuel on the temperature to which its mixtures with oil must be heated to effect its removal.

When heated to 100 deg. cent. (212 deg. fahr.) in the presence of its own vapor, about 20 per cent of commercial gasoline will evaporate; when heated to 150 deg. cent. (302 deg. fahr.), about 67 per cent evaporates. When other vapors are present, as is the case in the simple distillation used to remove the fuels from the oil, the partial pressure of the fuel is lowered by its dilution in the air and at the same temperature a greater volume

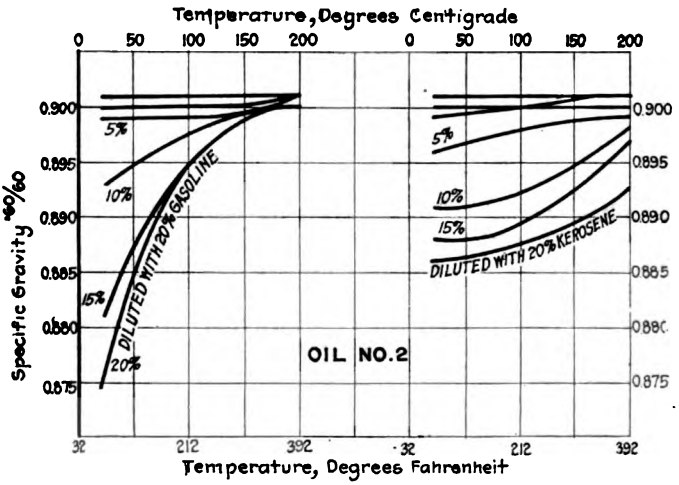

FIG. 9—HOW DILUTING A LUBRICATING OIL WITH VARYING PERCENTAGES OF GASOLINE AND KEROSENE AFFECTED ITS SPECIFIC GRAVITY

of the fuel will evaporate than when its vapor pressure is higher. The same explanation will show why little, if any, of the kerosene is removed when the diluted oil is heated to 100 deg. cent. (212 deg. fahr.), and an appreciable amount at 150 deg. cent. (302 deg. fahr.) and 200 deg. cent. (392 deg. fahr.), although when heated in the presence of its own vapor only 20 per cent of the kerosene vaporizes at 200 deg. cent. (392 deg. fahr.), and but a very small amount at 150 deg. cent. (302 deg. fahr.) and 100 deg. cent. (212 deg. fahr.).

The values for the specific gravities of the diluted mixtures are given in Figs. 8 to 11, to show that specific gravity can be used to estimate roughly the changes in viscosity resulting from fuel dilution. It should, however,

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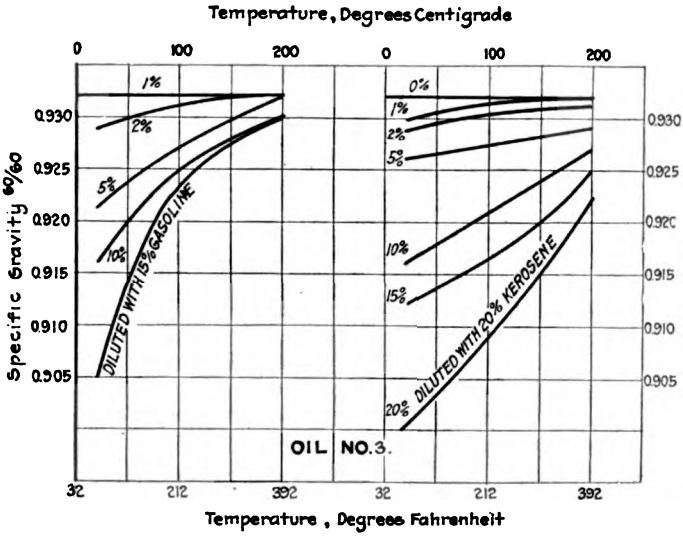

FIG. 10—CHANGE IN THE SPECIFIC GRAVITY OF A LUBRICATING OIL CAUSED BY DILUTION WITH FUEL

be carefully borne in mind that, in general, specific gravities and viscosities are not proportional.

The results of the experiments with the simplest method of distillation show that there is no necessity for

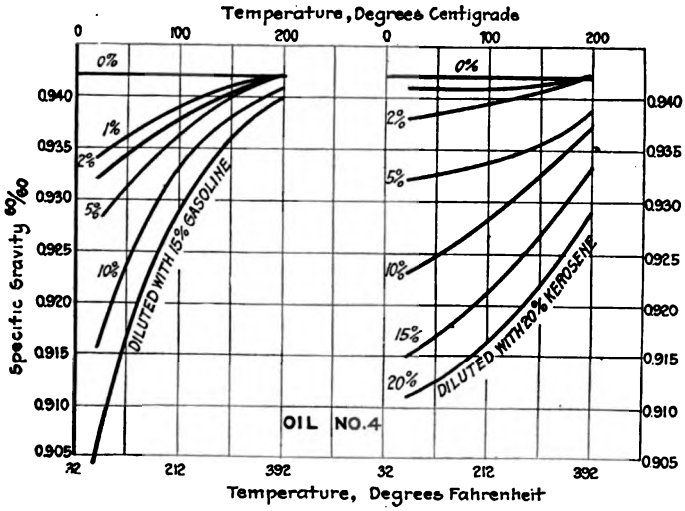

FIG. 11—THE ADDITION OF VARYING PERCENTAGES OF GASOLINE AND KEROSENE TO A LUBRICATING OIL AFFECTED ITS SPECIFIC GRAVITY

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highly developed distillation methods when the present-day commercial engine-gasoline or a more volatile fuel is to be removed from lubricating oils, provided, of course, that the composition of the oil will permit its heating to 150 deg. cent. (302 deg. fahr.) or 200 deg. cent. (392 deg. fahr.). There is, however, a need for the use of better methods for the removal of kerosene and similar less volatile fuels from the oils.

Effects of Time and Exposed Area

With this in view, several further experiments were carried out to indicate the possible improvements through simple changes in the method of distillation. In this series the effect of changes in the time of heating and in the area of free surface exposed, on the removal of fuels from oil was studied. An engine oil of medium viscosity was diluted with various percentages by volume of the same two fuels previously used, engine gasoline and kerosene. A sample of about 100 c.c. of the diluted oil was heated in a 200-c.c. beaker to 100 deg. cent. (212 deg. fahr.), and held at this temperature for 2 min. It was then allowed to cool and its specific gravity was measured. This procedure was then repeated, but for different lengths of time; for 5 min. in the first instance and 10 min. in the second. This series was then repeated with a fresh sample of oil at 150 deg. cent. (302 deg. fahr.), instead of 100 deg. cent. (212 deg. fahr.), and again with another sample of oil at 200 deg. cent. (392 deg. fahr.).

To show the effect on the removal of the fuel of a change in the area of the free surface of the oil, the series of operations just described was repeated in an evaporating dish giving about four times the area of exposed oil-surface. Another method of increasing the effective area of oil surface for evaporation would consist in passing a stream of air through a comparatively deep layer of oil.

The results shown in Figs. 12 and 13 are typical. In these figures specific gravity is used to indicate the extent to which the fuel had been removed, in the absence of a complete series of viscosity readings that could not be made in the time available. The validity of this use of specific gravity as an index of viscosity was checked, however, by viscosity measurements.

The results given in Fig. 12 are with 10 per cent of kerosene as a diluent. They show clearly that the time

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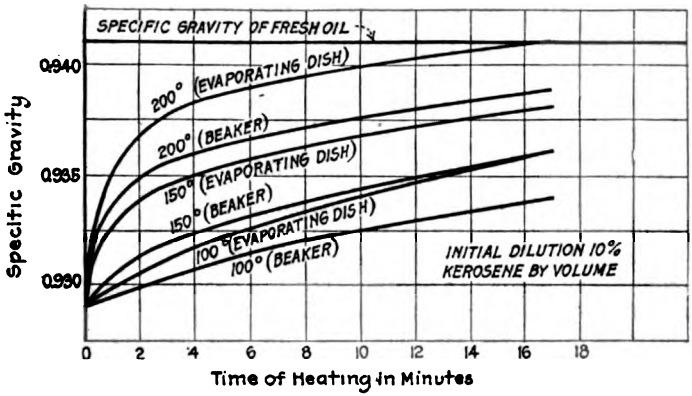

FIG. 12—HOW THE CHANGE IN THE SPECIFIC GRAVITY OF A MIXTURE OF LUBRICATING OIL AND KEROSENE CAN BE USED TO INDICATE TO WHAT EXTENT THE LATTER HAS BEEN REMOVED

of heating and the exposed area of oil surface have very marked effects on the removal of fuel from the oil. The results of the experiments made, using greater and smaller dilutions with kerosene, showed the same marked increase in amount of fuel removed with increase in surface exposed. They also showed that the larger the fuel dilutions, the more pronounced was the effect of the time of heating.

For commercial gasoline, it is shown in Fig. 13 that for a given percentage of fuel removed a lower temperature may be used, provided that the time of heating or the surface exposed be increased. This is an important fact, not only because of possible oxidation of the oil at the high temperature, but also because, after an oil has

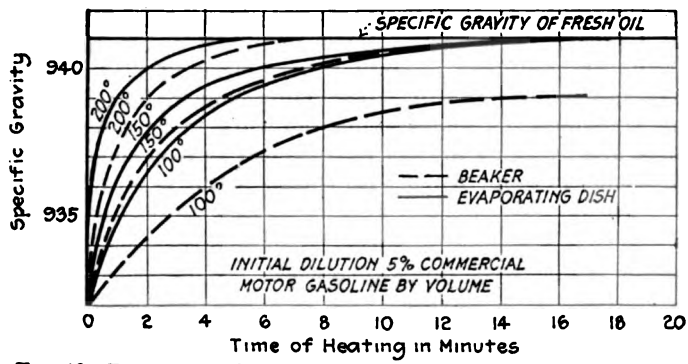

FIG. 13—RESULTS OF EXPERIMENTS TO DETERMINE THE TIME AND TEMPERATURE REQUIRED TO REMOVE GASOLINE DILUENT FROM LUBRICATING OIL

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been heated to 150 or 200 deg. cent. (302 or 392 deg fahr.), to remove the fuel, it must be cooled before it can be used. The importance of the use of the lowest practicable temperatures for restoring oils is therefore clear.

Conclusions

The possibilities so far shown by the investigation would warrant efforts on the part of automotive engineers toward the development of devices for duplicating the laboratory results in engines, but the data are insufficient to indicate how far the continuous regeneration can be carried in a practical way. A few suggestions as to a possible practical form of this apparatus, which it is hoped to develop in the course of the investigation at the Bureau of Standards, are given in the appendix.

As a conclusion from the data at present available, it can be stated that oils contaminated with different fuels, such as commercial gasoline and kerosene, can be restored entirely or at least their viscosity can be greatly increased by laboratory methods that could probably be incorporated in practical designs for application to present types of engine. Although devices constructed with this in view would give immediate relief, their successful operation might offer increasing difficulties with a further decline in the volatility of commercial engine fuels, which is a very likely condition in view of the steadily rising demand.

For this reason the ultimate solution of the problem lies, in my opinion, along the line of new departures in engine design, preventing the accumulation of liquid fuel in the cylinders and the lubricating system. Although it is difficult to foretell the line of development which will lead eventually to the goal, the combined genius of hundreds of engineers spurred by the need of one of our greatest industries will, undoubtedly, find it. The Bureau of Standards, by undertaking the work in part reported here and by being always in readiness to help solve other problems in cooperation with the industry, is only trying to "do its bit" in the great struggle toward a more efficient utilization of our natural resources.

Appendix

It is obvious that if a device for restoration of lubricating oils which is adaptable to engines now in service, could be put upon the market, a decided saving in fuel cost would result to the users because of the possibility

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of running on lower-grade gasolines or even on kerosene. For this reason a self-contained appliance that is easy to install would be preferable.

The exhaust gases should be used as the source of heat supply and led through a pipe coil in a small vessel containing the oil or preferably, on acount of ease of cleaning, through a heating jacket surrounding the vessel. The vessel should be connected with the lubricating system and its capacity in relation to the rate of oil feed so chosen that its contents will be completely renewed in 20 to 30 min. A thermostat of any design now readily obtainable on the market at a low cost could be used to keep the temperature constant at the desired degree. In the case of force-feed lubricating systems, an adjustable by-pass could take care of the oil feed and, by allowing the thermostat to regulate both this and the heating valve, the operation of the device could be rendered practically automatic. A small pipe, connecting the vapor space of the oil container with the intake manifold, would prevent wasting the recovered fuel, and a discharge pipe provided with cooling fins would prevent the return to the crankcase of unduly hot oil. Where there is no oil-pump in the lubricating system, one actuated by manifold suction, such as is now used on some motor cars for the gasoline supply, could be made a part of the appliance.

In newly designed engines a pipe coil heated by the exhaust gases and immersed in the oil-sump, coupled with artificial ventilation of the crankcase, might prove an easy and inexpensive way of retarding undue dilution of the oil. In cases where it is desired to draw air through the oil while it is being heated, the vacuum in the suction manifold could again be usefully employed. This method should be used cautiously, however, as contact with air at high temperatures such as 300 deg. fahr. and over, is likely to cause premature deterioration of the oil.

The saving effected with engines requiring a frequent renewal of the oil on account of excessive dilution, would soon pay for the cost of the additional equipment, even at the present high price of lubricants.

THE DISCUSSION

NEIL MACCOULL:—The dilution of lubricating oil is such a common complaint with kerosene-burning engines and even with engines burning the present-day commercial gasoline, that it is a subject worthy of thorough study. I am particularly glad to hear Mr. Kramer's

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refutation of the false impression entertained by some, that the thinning of oil in service is caused principally by cracking rather than by dilution with fuel.

It is natural that lubrication engineers should be among those most interested in an investigation of the causes and effects of dilution, and accordingly the company with which I am connected has been conducting somewhat similar research, although the study was made from a slightly different angle. Our experiments are divided into three different classifications

(1) The physical changes which take place when a lubricating oil is mixed with various quantities of fuel
(2) The effect of these changes upon the performance of an engine
(3) The rate at which these changes occur on the road

We find it particularly convenient to plot curves such as Fig. 14, showing the relation between gravity and viscosity for mixtures of fuel with each oil in which we are interested. With such data it is a simple matter to determine accurately the extent to which the viscosity of an oil has fallen, simply by the use of an hydrometer. A point of considerable interest is that such curves made for gasoline or kerosene mixtures are so nearly coincident that they can be considered identical for all practical purposes. On the same sheet we have another curve showing the relation between gravity and the percentage of kerosene, so that a determination of the equivalent kerosene content can also be made by the hydrometer. One would naturally expect that the curve between kerosene content and gravity would be a straight line, but it is slightly curved. These curves are more practical for determining kerosene content than distillation methods, because any separation by a single distillation cannot be complete. A little of the oil goes over with the fuel, while a little of the fuel remains with the oil. It is not at all unusual for the final boiling point of the fuel to be higher than the initial boiling point of the oil.

In order to determine how serious the effect of dilution is upon engine performance, a dynamometer test was made on a No. 7-R Continental engine that had been run about 300 hr. on various tests and was in excellent condition. The oil used was Texaco Medium of 300-sec. Saybolt viscosity at 100 deg. fahr., and the various percentages of dilution were made by mixing kerosene with the oil. Strange as it may seem, the power increased and

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the fuel consumption decreased as more and more kerosene was added, up to about 40 per cent, when the viscosity of the mixture was only 52-sec. Saybolt at 100 deg. fahr. With this mixture the power and fuel consumption were about 5 per cent better, at 2000 and at 800 r.p.m., although the oil pressure had dropped from 15 to 10 lb. One must be cautious, however, about drawing conclusions from this test until the results are compared with

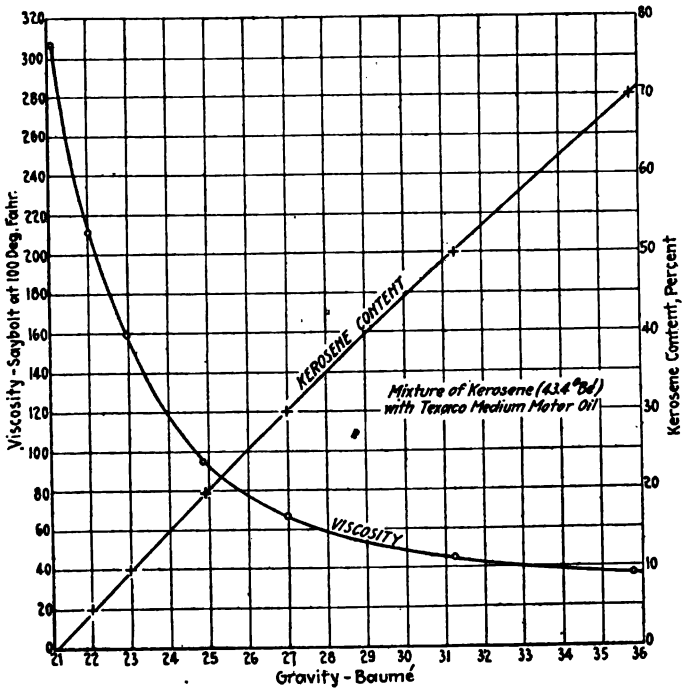
Viscosity - Saybolt at 100 Deg. Fahr.
Kerosene Content, Percent
Gravity - Baumé
KEROSENE CONTENT
VISCOSITY
Mixture of Kerosene (43.4° Bé) with Texaco Medium Motor Oil

FIG. 14—RELATION BETWEEN THE VISCOSITY AND THE SPECIFIC GRAVITY OF A MIXTURE OF LUBRICATING OIL AND FUEL

tests on other engines. Also it is not at all certain that a straight-run oil of 52-sec. Saybolt will act the same as the oil of 300-sec. Saybolt viscosity diluted to 52-sec. Saybolt.

Tests were made also on the road with a commercial vehicle, covering the same route with the same driver and approximately the same load every day. Conditions for a good road test could hardly have been more ideal. These tests and repeated checks showed results which at first glance are paradoxical. As shown by Fig. 15, the

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increase of kerosene found in the oil each successive day was less and less until finally it became negligible. The first day, after about 100 miles, so much kerosene found its way into the oil that there was apparently more oil in the crankcase after running than before starting. The reason for this was that the quantity of oil burned was less than the amount of kerosene which found its way into the oil. The second day showed a small consumption, which increased each day until it remained nearly constant at the time the kerosene content ceased to increase. The results indicate that there is probably an evaporation phenonemon occurring in the crankcase, the quantity of fuel evaporating increasing with the percentage present in the oil, until the rate of evaporation is equal to the rate of kerosene influx, after which no increase in the kerosene content will occur.

To check this theory of evaporation a carefully regulated stream of air was bubbled through a mixture of 20 per cent kerosene and 80 per cent Texaco heavy motor oil, with temperature held constant at 150 deg. fahr., representing the maximum temperature of the oil meas-

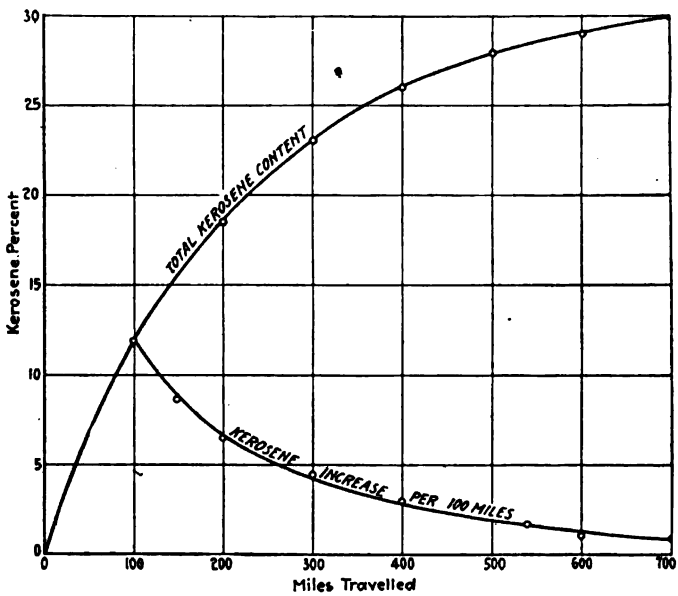

FIG. 15—HOW THE AMOUNT OF KEROSENE FINDING ITS WAY INTO THE CRANKCASE BECOMES LESS AND LESS WITH THE LENGTH OF RUNNING

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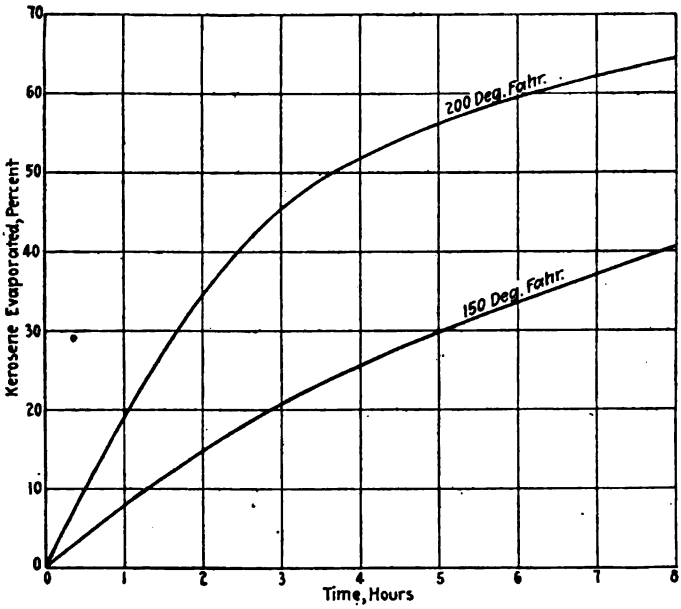

FIG. 16—RATE OF EVAPORATION OF KEROSENE FROM A MIXTURE OF LUBRICATING OIL AND KEROSENE AT DIFFERENT TEMPERATURES

ured during the road tests. The results are shown in Fig. 16, together with a similar test run at 200 deg. fahr. After 8 hr., it will be noted over 40 per cent of the kerosene was evaporated even at this low temperature, which was about 200 deg. fahr. below the initial distilling temperature of the kerosene.

It is clear that the phenomena of oil dilution are not at all what they are usually assumed to be and further experimentation is much needed, to determine not only the effects of dilution but also the laws covering the rate of influx of fuel into the oil and their relation to features of design.

D. G. ROOS:—I can bear out the statements in regard to the amount of dilution of the crankcase oil reaching a constant value. We have been making a series of experiments, operating trucks on kerosene, and we found that the same phenomenon occurred. We also found that plenty of breather capacity seemed to help it. It has also been demonstrated that an oil-pan which is exposed in cold weather to ice-cold air flowing under the car has a tendency to make matters worse, and if a protecting pan

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is put under it, so that it can be kept warm, the conditions are better.

J. H. HUNT:—I have carried out a good many experiments along the same general line. Some of the data of these experiments have been published.[3] I am convinced that the problem will be completely solved when we start with the engine sufficiently heated, in conjunction with a properly-heated distribution system, so that we can start the engine and operate it after starting with normal adjustment of the carbureter. After considering all of the devices which have been proposed for taking care of crankcase dilution, I think that the problem is better handled with something to take care of the starting and initial running, thus preventing the dilution from occurring, than by adding a device of the type under discussion. Some experiments have shown that the situation can be handled in the way that Mr. Kramer has suggested. The best results, in my opinion, will be obtained by less equipment, by putting on some device which will enable us to start without any choking whatever and then operate smoothly right from the start, regardless of the temperature of the engine. The above statements apply to the fuels now used in automobile engines. With fuels as heavy as kerosene, conditions might be different.

H. W. SLAUSON:—The problem of oil dilution is a serious one, especially as it affects the ordinary user. He is warned by the manufacturer to drain the crankcase every 500, 800 or 1000 miles. Very few of us do it. The cost involved is not great, but each car owner feels that the 3 to 4 quarts and sometimes 5 to 6 quarts of oil that he is directed to throw away ought to be perfectly good. Until we can operate our cars so that there will not be this crankcase dilution, is there a possibility of reclaiming this oil commercially?

H. C. GIBSON:—Mr. Kramer has painstakingly shown us which features of the dilution difficulty are of real importance. It is regrettable that we cannot yet know the final determination resulting from the use of the various projected apparatus referred to. Spontaneous decomposition of the oil film on cylinder walls and of pools on pistons is expected because of the temperature and pressure of combustion, but in ordinary methods to crack oil in appreciable quantity requires exposure for considerable time, far longer than the time of two strokes of a piston. The results of a test where the actual oc-

[3] See TRANSACTIONS, vol. 14, part 2, p. 530.

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currences of normal operation of an engine are reproduced will be most instructive, if only to eliminate a disturbing thought from our minds. I do think that immediate relief in preventing oil dilution is not unattainable, or solely dependent upon the development of new engines. Almost all engines now in use can be satisfactorily fitted with means for evaporating the fuel prior to entry to the cylinder. It is done; in fact, in some tests where the fuel was kerosene, the oil viscosity increased consistently just as in the case of the aviation engine referred to in the paper. Even if fuel-mixture heating devices prevent dilution when they are hot and performing their work properly, there will always be some dilution resulting from starting operations in the less-expensive cars. Any dilution is undesirable and the well conceived and well-worked-out devices described in the appendix to Mr. Kramer's paper will be a boon to the industry and, when allied with properly-designed mixture heaters, form a combination well able to solve the difficulties of dilution.

PROF. O. C. BERRY:—The kerosene-burning tractors have had a great deal of trouble with lubrication, due to kerosene diluting the lubricating oil. In this connection a series of tests conducted by the Purdue Engineering Experiment Station will be of interest. These tests showed that the surface of a steel plate had to be held at a temperature of about 625 deg. fahr. in order to be most effective in vaporizing kerosene, and that the rate of vaporization decreased very rapidly as the temperature was lowered. If the rate of vaporization at 625 deg. fahr. be represented by 100 per cent, then at 500 deg. fahr. it will be about 20 per cent, and at 450 deg. fahr. about 6 per cent.

To show the bearing of this information upon the design of the hot-spot intake manifold, an engine was operated with all of the intake air impinging on one side of a steel plate and all of the exhaust gases on the other. The speed and load of the engine were changed from maximum to minimum conditions, but the temperature of the plate remained nearly constant at about 325 deg. fahr. I am convinced that the temperature is too low in the metal in nearly all of the hot-spots now used for carbureting kerosene.

To my mind the most satisfactory design of a hot-spot is the one that will allow the liquid portions of the fuel to come in contact with the manifold, but will keep

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most of the air away from it. This will prevent the mixture from becoming so hot and the metal in the hot-spot will not be cooled down so much that it will take on more nearly the temperature of the exhaust gases. The latter will vary from about 500 to 1200 or 1400 deg. fahr., but will never be hot enough to ignite the gases in the intake manifold.

R. W. A. BREWER:—The remarks of Professor Berry relative to means of preventing fuel from mixing with lubricating oil are liable to lead one astray because he has evidently in mind a matter of normal impingement of vapor on one side of a flat plate and heated gases on the other side of a flat plate. There are many other ways of bringing these two influences together. Lines of work that are being followed do not employ this system of impingement at all; so that the arguments of Professor Berry do not hold. It is possible by keeping the air insulated from the heated walls to treat only the liquid particles; to treat them not by normal impingement but by other means which are effective in preventing the liquid from entering into the crankcase.

A MEMBER:—How does Professor Berry arrive at the figure he mentioned for the vaporization of kerosene?

PROFESSOR BERRY:—The tests were carried out in this way: A steel plate ½ x 4 x 10 in. was placed over an electric heating element and so arranged that its temperature could be controlled accurately. A depression was milled in the top of the plate to receive the fuel and holes were drilled in the plate close to the depression, to measure the temperature of the metal in contact with the fuel. The fuel was siphoned out of a small glass beaker on one pan of a set of chemist's balances, and allowed to flow into the fuel well on the hot plate. The rate of flow was adjusted until the amount of fuel left in the well remained constant. The time required to vaporize a known weight of the fuel was then recorded, together with the corresponding temperature of the steel plate. Since the wetted area in the fuel-well was known, the rate of vaporization per square inch of hot surface could be determined for the various metal temperatures.

MR. MACCOULL:—I believe there is much confusion between evaporation and boiling. Kerosene, if it is heated in the presence of air or any other gas, can be evaporated at a lower temperature than that at which it will boil. That is what I had in mind in my previous dis-

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cussion, when I referred to an experiment where a large percentage of kerosene was *evaporated* at a temperature about 200 deg. fahr. below its boiling point.

SYDNEY BEVIN:—I believe that this paper is an excellent start along proper lines, but that it has not gone far enough. Anyone familiar with lubricating oils and gasoline will realize that dilution curves of lubricating oils with gasoline and kerosene can be drawn fairly accurately without experiment with the actual mixtures to determine their viscosities. Knowing the viscosities of the oils under test and the fuels under test, it is possible without any experiment whatever to demonstrate that "a higher percentage of dilution would be permitted with the lighter oil." The conclusions reached seem to indicate that gasoline evaporates from crankcase lubricants as fast as it reaches them, in an engine equipped with a proper breather. My belief is that the problem is one of eliminating the kerosene or equally heavy fuel from the crankcase oil, as that portion of the gasoline which finds its way past the pistons is the heaviest fraction of the fuel. The other fractions will have split off to burn in the cylinder. It would seem that a device for the continuous restoration of lubricating oils would have to be constructed with much care and with an eye to the filtering-out of the oil entering this restoring device and the precipitation of free carbon from the lubricant. I think that it would be simpler to have apparatus installed in every garage to rectify the engine oil, drawing it off periodically.

G. A. KRAMER:—It should be understood that when evaporation is mentioned in the paper, evaporation is meant and not boiling; it is like some wet substance drying in air which does not require heating to the boiling point of water when exposed to an air current; it will dry at much lower temperatures.

As to the possibility of recovering used oils, if by recovery of used oils is meant only the expelling of the fuel present in it, that is very simple and can be performed by any distilling process. A small still could probably be used. By raising the temperature of the oil to a high enough degree to evaporate the largest proportion of kerosene, which would be somewhere near 550 to 600 deg. fahr., the oil could be recovered. If it is a question of recovering oils which are deteriorated in other ways, that requires more complicated apparatus which probably would be too costly and not easy to install in every garage.

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THE MEASUREMENT OF VEHICLE VIBRATIONS

By Dr Benjamin Liebowitz[1]

The five fundamental criteria of the performance of a motor vehicle as a whole are stated. Riding comfort is investigated at length with a view to determining methods of measurement of the two classes of vehicle vibrations that affect the riding qualities of a car, so that suitable springs can be designed to overcome them. The underlying principles of the seismograph are utilized in designing a specialized form of this instrument for measuring vehicle vibrations, the general design considerations are stated and a detailed description is given. This is followed by an explanation of the methods used in analyzing the curves obtained, thus making possible a standardized measurement of riding comfort. The factors determining riding comfort are then analyzed in connection with spring-development work, the most important are summarized and the preliminary experimental results of those directly determined by the seismograph are outlined. The forced and the free oscillations of a vehicle body are mathematically analyzed in Appendix I. Two theorems are developed in Appendix II; one for stiffness and the other for static deflection of lever-suspension springs.

THE performance of a motor vehicle as a whole is determined by five fundamental criteria,[2] as follows:

(1) Range of operating speed
(2) Acceleration
(3) Hill-climbing ability
(4) Fuel economy
(5) Riding comfort

Methods of measurement have been thoroughly worked out for the first four of these, but the fifth has hitherto been left to shift for itself.

There are in general two classes of vibrations that

[1] Chief engineer, Monidyne Vehicle Suspension Co., New York City.

[2] Methods of Comparing Automobile Performance by Walter T. Fishleigh, S. A. E. Transactions, vol. 12, part 1, p. 259.

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affect the riding qualities of a car: (*a*) those originating from the road and (*b*) those originating in the chassis itself, such as engine vibrations. Each of these may be resolved into vertical, longitudinal and transverse components. From the standpoint of riding comfort the most important are the vertical vibrations, due to the road, and this paper deals with these.

The usual method of testing the riding qualities of a car is to ride in it and find out how it feels. But unfortunately this depends largely upon how the rider feels. Furthermore, in such tests there is always occasion for a difference of opinion. The main difficulties lie in first trying to estimate the degree of discomfort and then trying to remember it.

Engineers have long recognized the complete unreliability of the "feel" test, and some efforts have been made to work out better methods. Thus a water barrel or similar device has been used and the unit of measurement was then the amount of water left in the barrel after a test run. But large slow swings of the car body can obviously have more effect in this method than a series of short sharp shocks that would be more disagreeable to the passenger.

Attempts have also been made to use a spring-supported weight, but as will presently appear these instruments fell far short of meeting the requirements and gave a resultant curve in which the vehicle-body vibrations and those of the weight were hopelessly intermingled.

Photographic methods have been used both in the laboratory and on the road, but they are very laborious, slow and expensive; furthermore, owing to the thickness of the line on the plate and the necessarily large photographic reduction, only the large motions of the body can be successfully examined.

No determined effort appears to have been made heretofore to produce an instrument that could be set in the car and driven over an ordinary road, and which would accurately record the full-size vertical motions of the vehicle body. To meet this situation, particularly in connection with my own work on spring suspensions, I have developed a seismograph which traces the time-displacement curve of a point in the vehicle body. From this curve the vertical velocities, accelerations, amplitudes, periods and damping, in short, all the most important physical factors that determine riding comfort, can be accurately measured.

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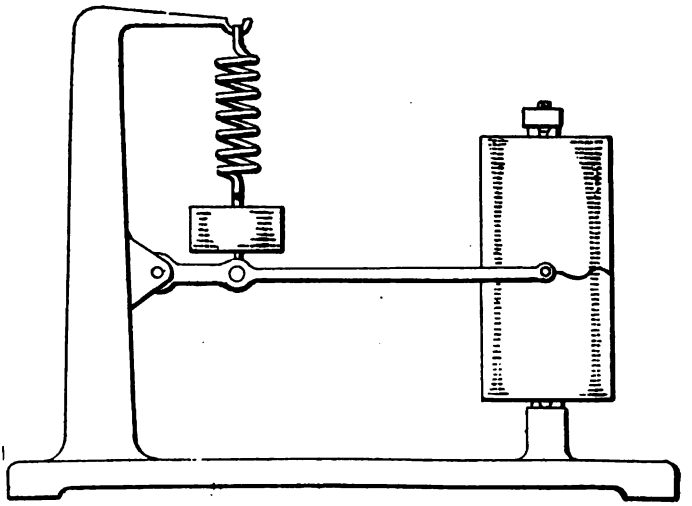

FIG. 1—A VERTICAL-COMPONENT SEISMOGRAPH

UNDERLYING PRINCIPLES OF SEISMOGRAPH DESIGN

The problem of designing a seismograph for vehicle vibrations is fundamentally the same as that for earth movements, namely, to provide a point that shall remain substantially at rest while things about it move. From a practical standpoint, however, the two problems are quite different. To clarify the principles of the vehicle seismograph, the means used by seismologists for recording vertical vibrations may be briefly described. A vertical-component seismograph consists simply of a mass, or "inertia element," hung from a long helical spring and connected by amplifying levers to a marker, which traces the relative motion between the weight and the earth on a slowly rotating smoked drum. The mass is allowed to move as it will in a horizontal plane; but since the motions are small, there is no difficulty in making the connections so that only the vertical vibrations affect the marker. (See Fig. 1)

The basic theory is this: If the suspended weight has a sufficiently long period of vertical oscillation, the frame of the instrument, including the point of support of the weight, will partake of the vertical vibration which the surroundings are undergoing without imparting any appreciable movement to the weight itself. In other

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words the weight or inertia element provides a "dead-point," relative to which the vibrations of the instrument, and hence those of the surroundings, can be recorded. Of course, the inertia element cannot be maintained absolutely at rest under the disturbances due to the motion of its point of support. The question therefore arises: How long must the period of the inertia element be in order that its motions shall be negligibly small?

The mathematical investigation of this problem is given in Appendix I. The net results may be stated thus: The period of the inertia element must be long in comparison with the longest period of oscillation that it is desired to record. In the appendix it is shown that if the period of the weight is five times the longest period of oscillation to be recorded, the error introduced is 1 in 25 or 4 per cent. This is entirely satisfactory for all practical purposes. In the appendix it is also shown that the inertia element will undergo a free oscillation whose amplitude is one-fifth of the amplitude of oscillation of the vehicle body, if the ratio of periods is 1 to 5, as before. This free oscillation is of no inconvenience whatever, as shown in the appendix, because it amounts to nothing more than a slowly-wandering zero.

The longest free period we meet with in automobiles can reach 0.7 sec. or more; hence, from the foregoing considerations, a seismograph for motor vehicles should have a free period of 3.5 sec. or longer. The static deflection which corresponds to a 3.5-sec. period is computed from the well-known period formula:

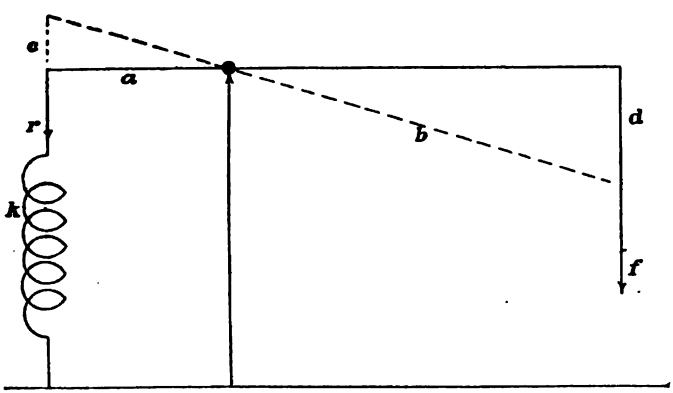

FIG. 2—AN ELEMENTARY FORM OF LEVER SUSPENSION

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$$\text{Period} = 2\pi\sqrt{\frac{M}{K}} = 2\pi\sqrt{\frac{\delta}{g}}\text{, where}$$

M is the mass of the inertia element
K is the stiffness of the spring, and
δ is the static deflection

It develops that to provide a 3.5-sec. period, a static deflection of 120 in. is required. In other words, if this seismograph were built like the designs of the earth instruments (Fig. 1), we would have a structure about 14 ft. high. The practical problem is therefore to provide a large deflection within a small space.

A simple lever offers a satisfactory solution. The lever suspension consists of a pivoted rod (Fig. 2) whose arms are a and b inches long. A spring is fastened at one end and a load f is applied at the other. In Appendix II the following two theorems are derived:

(1) The lever suspension acts like a simple spring whose stiffness is equal to the stiffness of the actual spring divided by the square of the lever-arm ratio

(2) The lever suspension acts like a simple spring whose static deflection is equal to the static deflection of the actual spring multiplied by the lever-arm ratio

In other words, the lever suspension multiplies the static deflection of its spring by the lever-arm ratio.

To use a practical example, suppose the lever-arm ratio is 20 to 1 and suppose that, when the lever is horizontal, the coil spring is stretched 6 in.; then the lever suspension will act like a simple spring whose static deflection is 6 times 20 = 120 in.

The lever suspension is a very old device, but its principal advantage of furnishing a large deflection in a small space does not appear to have been fully realized, and, as far as I know, this feature has not received recognition in seismograph design. This form of suspension was tried out some time ago as a vehicle spring, but although it offers interesting design possibilities, its main advantage cannot be utilized in this application. For the static deflection is limited, not by what the spring-makers can furnish, but by the clearance which the chassis-designer provides. We cannot use a 7-in.

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deflection with a 3.5-in. clearance and have a car that will perform satisfactorily on rough roads, unless the spring has a rising characteristic, that is increasing stiffness with increasing deflection.

General Design Considerations

Having found what period is necessary for a practical vehicle seismograph and how to obtain that period in a practical manner, the remaining design factors to be considered are the range of movement, the weight of the inertia element, friction and the manner of suspension.

When the going is fairly rough, the movement of an automobile body at a point over the rear axle, either up or down from the neutral position, will frequently reach 3 in. or more. To care for such movements, plus the slightly-wandering zero, a range of movement of about 10 in. should be provided in the seismograph. A larger range would seldom be made use of and would add considerably to the weight and bulk of the instrument.

The weight of the inertia element is determined by frictional considerations. Suppose the friction was constant and that its total value, measured at the inertia element, was 1 per cent of the weight of the inertia element. Then the acceleration necessary to overcome this friction would be 1 per cent of the acceleration due to gravity, 0.32 ft. per sec. per sec. The instrument would then have a constant error in acceleration of 0.32 ft. per sec. per sec. This is negligible, for it requires an acceleration of several feet per second per second to be at all perceptible.

The friction in the pivots increases with the weight of the inertia element but can be minimized by the use of knife-edges. The pencil or marker friction, however, is a very variable factor. To make sure that it shall always be small compared with the weight, the latter should be large, say 10 lb. This does not materially increase the bulk of the instrument, which is determined principally by the period, the range and the requirements of rigidity.

But it should be pointed out, in passing, that sufficient friction for damping will exist in the pivots, rollers and marker. Moreover, the last can be varied so that some control of the damping is readily possible.

The manner of suspending the inertia element remains to be considered, as to whether it should be guided so as

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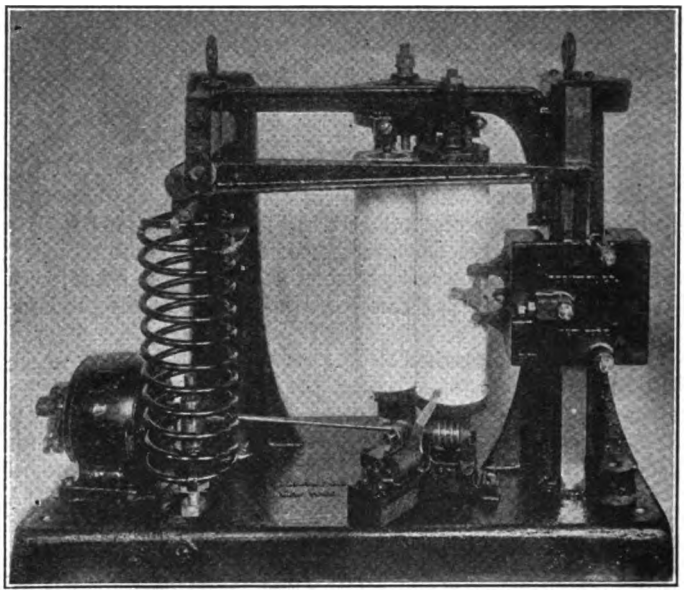

FIG. 3—EARLIER FORM OF SEISMOGRAPH FOR VEHICLE VIBRATIONS

to move in a strictly rectilinear path, or rigidly fastened to the long arm of the lever suspension so that its path will be the arc of a circle. In this connection we must consider the "kick" due to the inertia reactions of the rotating parts inherent in the lever suspension. It is unnecessary to investigate this matter here, except to point out that if the inertia element is guided so that it moves up and down without rotating, and the supporting levers are made very light, any errors due to rotary inertia reactions will be negligible.

DETAILED DESCRIPTION OF THE INSTRUMENT

Fig. 3 is a photograph of an earlier form of the seismograph; Fig. 4 is the present form. In the light of the foregoing discussion, only a brief description is necessary. *A* is the inertia element, equipped with ball-bearing rollers. Fastened to the rigid post *C* is the hardened and ground guide *B* provided with grooves in which the rollers on *A* operate. The inertia element is connected to the long arm of the rocker-pivoted aluminum lever *F* by the connecting-rod *E*. The spring *H* and the adjustment *G* complete the lever suspension. The rolls *J* and

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L and the electric motor *K* are the principal parts of the paper mechanism. *N* is the marker attached to the inertia element *A*. A hard pencil lead is fairly satisfactory for the purpose, but a brass stylus and prepared paper are better. Ink can be used, but it does not give a fine line and is troublesome.

The paper speed is adjustable up to 9 or 10 in. per sec. High paper-speed is desirable, because the more the record is drawn out the more accurately it can be analyzed. A half-second clock and a time-marker, electrically operated by a connection with the clock mechanism, indicates half-seconds directly on the paper. This makes it possible to determine accurately the speed of the paper and to take into account variations in the speed.

The mode of operation of this instrument can be illustrated by an analogy. Imagine a test road with an accurately-built fence running alongside and a marker rigidly fastened to the body of the vehicle under test. Let the automobile be driven along the road at a constant distance from the fence, so that the marker always touches it. With the fence unaffected by the road vibrations due to the passage of the vehicle and with a constant speed, a fairly accurate record of the vertical vibrations of the vehicle body will be obtained. In the

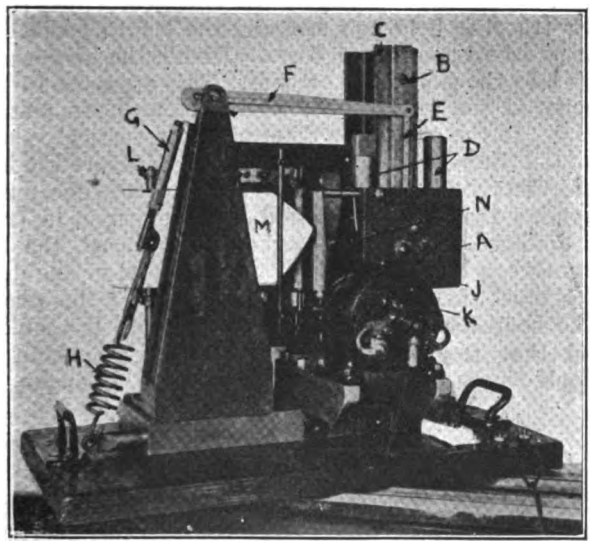

FIG. 4—PRESENT FORM OF SEISMOGRAPH

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seismograph, conditions are in effect inverted, as if the marker was attached to the fence and the record-strip or paper-roll was fastened to the car body. The record traced by the seismograph is therefore inverted. When the car body moves up the paper-roll likewise moves up and, since the weight with marker attached is stationary, the slope of the line traced is downward.

The record traced by the seismograph shows the up-and-down oscillation and vibration of the vehicle body at a glance. To realize the full value of the instrument, however, the records must be analyzed carefully. The principal thing to seek, as will be pointed out, is acceleration, but amplitude and damping of the free oscillations are also very important.

Methods of Analyzing Curves

The seismograms can be roughly analyzed for acceleration with ordinary drafting instruments. Thus, in Fig. 5 let the curve represent an enlarged portion of the record. Select two points p and q on the curve, where the curvature is most rapid; draw the tangents pb and qd of any desired length and complete the right-angle triangles as shown. From the time marks note the time corresponding to the lengths pa and qc. Thus, if the paper travel is 5 in. per sec. and the length pa is 1 in., then pa corresponds to 1/5 sec. Divide the distance ba, in feet, by the time pa in seconds. This gives the vertical velocity of the vehicle body at the point p, in feet per second. In the same way determine the vertical velocity at q. Call these v_p and v_q respectively. Measure the horizontal distance from p to q and, from the time marks, determine the time t required for the paper to travel this distance. If a time-marker is not used, the time intervals can be determined from the speed of the drum, which must then be known. In the time t the velocity of the body has changed from v_p to $-v_q$ It should be noted that the tangents have opposite slopes in the example chosen; hence the acceleration is given by

$$\frac{v_p - (-v_q)}{t} = \frac{v_p + v_q}{t}$$

By choosing the distances pa and qc, each equal to ½ sec. for instance, the work can be considerably shortened. But this method, while satisfactory for rough work, has disadvantages; (*a*) it is not very accurate; (*b*) it gives

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the average and not the maximum acceleration between the two points; (*c*) points of maximum acceleration may easily be overlooked; (*d*) it does not permit the drawing of the acceleration curve, except with much labor.

Mathematically speaking, acceleration is the second derivative of the curve. This can be obtained quickly and accurately by an instrument called a comparator, such as astronomers use in measuring star photographs.

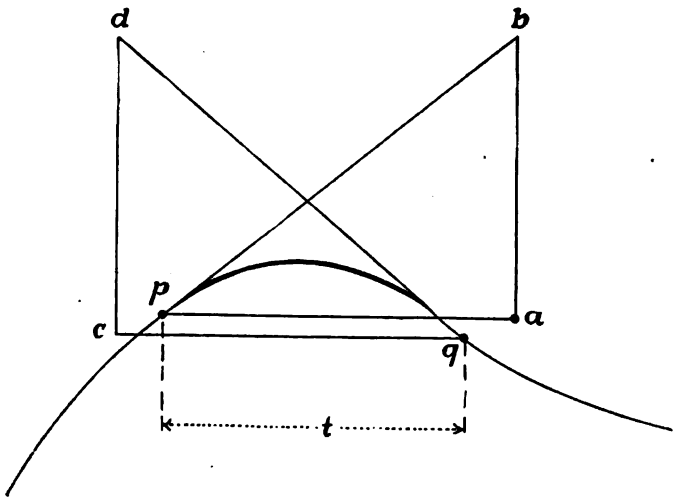

FIG. 5—METHOD OF ANALYZING SEISMOGRAPH CURVES

A simple form of this device has been designed specially for analyzing these curves (See Fig. 6). It consists of a base on which is mounted a micrometer slide with its axis horizontal and parallel to a finished surface on the base. Carried by this slide is a second micrometer slide, with its axis horizontal and perpendicular to the first slide. A magnifier equipped with cross-hairs is mounted on the second slide.

In use, the part of the record to be analyzed is tacked to a drawing-board with its edges parallel to the T-square. The particular portion to be considered is brought into the field of the magnifier of the instrument, which is set square by the T-square, and is fastened with pins so that it will not shift. The cross-hairs are then set on the line near the beginning of the "hump," as at *a* in Fig. 7, and the micrometer readings noted. The longitudinal slide is then shifted a known small distance,

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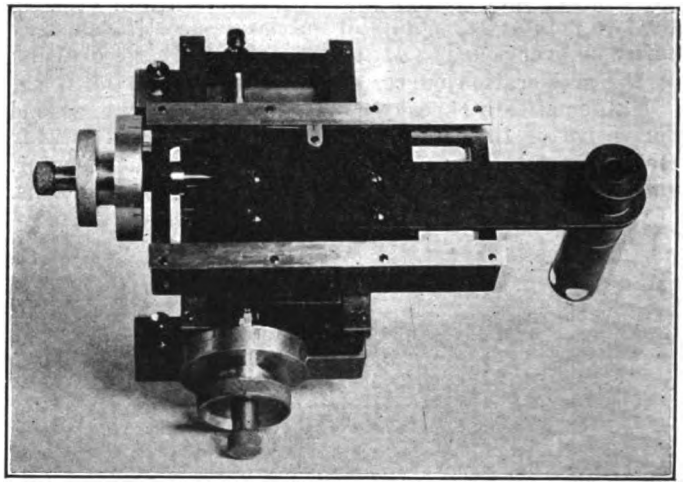

FIG. 6—COMPARATOR FOR ANALYZING SEISMOGRAPH CURVES

a to a', depending upon the curvature; the cross-hairs are then brought back on the line by moving the transverse slide through a' to b and the micrometer readings taken. In the same way set off b to b', determine b' to c, etc. To simplify the work, make a to $a' = b$ to $b' = c$ to c', etc., $= t$, where t is the time interval corresponding to these small distances. Denote the point midway between a and b by A, between b and c by B, etc. Then

$$\text{The velocity at } A = \frac{a'\,b}{a\,a'} = \frac{a'\,b}{t}$$

$$\text{The velocity at } B = \frac{b'\,c}{t}$$

$$\text{The velocity at } C = \frac{c'\,d}{t}$$

$$\text{The velocity at } D = \frac{d'\,e}{t}, \text{ etc.}$$

$$\text{The acceleration at } b = \frac{b'\,c - a'\,b}{t^2}$$

$$\text{The acceleration at } c = \frac{c'\,d - b'c}{t^2}, \text{ etc.}$$

By properly tabulating the work, the procedure is fairly

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rapid. By plotting the resulting accelerations, the acceleration curve can be drawn.

While the seismograph was primarily designed for use in spring-development work, it is equally useful in a number of other fields. For example, by keeping all other factors affecting riding qualities constant, a thorough study of tire performance can be made. Likewise, tire-substitutes, spring wheels, shock-absorbers, auxiliary springs and all devices affecting riding qualities, can be investigated with a degree of precision and certainty hitherto unobtainable. But above all, the instrument should be useful to the chassis-builder. Since the riding of the car he designs is affected by the sum of all the variables, it will enable him to set standards of riding qualities and to determine to what extent his product approaches these standards, even after it leaves his hands and has been in service. In short, the seismograph makes possible a standardized measurement of riding comfort, just as the measurement of the other four criteria of automobile performance has been standardized.

Factors Determining Riding Comfort

Having found out how to measure the most important factors that determine riding comfort, the next step is to determine the relative importance of each.

These factors may be listed as follows:

(1) Vertical acceleration, both with forced vibration or a short period and free vibration or a long period

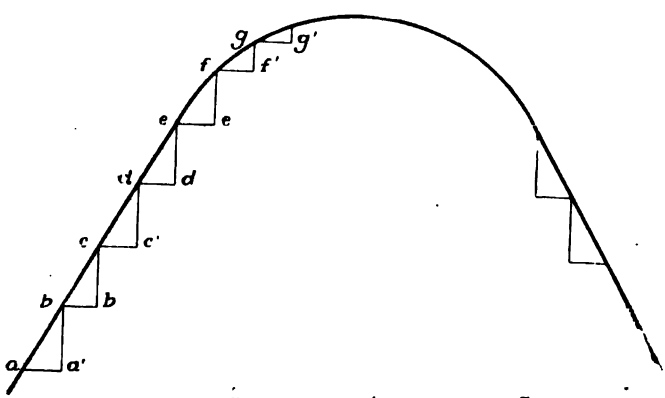

Fig. 7—Successive Steps in the Analysis of a Seismograph Record

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(2) Periods, both forced and free
(3) Amplitudes, both forced and free
(4) Damping, free only

There should also be included rotary acceleration, although this is not directly measurable by the seismograph, as will be pointed out.

Chassis and spring engineers have long recognized the great importance of upward acceleration. Thus, if a point in an automobile body is accelerated upward at the rate of 16 ft. per sec. per sec., or one-half the acceleration due to gravity, the passenger at that point experiences an upward force equal to half his weight; if the acceleration is 32 ft. per sec. per sec., the upward force on the passenger will equal his weight; etc. This neglects the cushioning effect of the upholstery. The stresses in the frame and in all the supporting members are likewise increased in the same proportion. There can, therefore, be no question of the basic importance of vertical acceleration, both forced and free, in the matter of riding comfort and the life of the chassis.

The question has frequently been asked, "Is acceleration the sole determining factor?" It is well understood that, speaking in terms of simple harmonic motion, the maximum acceleration is directly proportional to the amplitude and inversely proportional to the square of the period. Thus, a period of 1 sec. and an amplitude of 4 in. gives a maximum acceleration of 13.1 ft. per sec. per sec., which is about two-fifths the acceleration due to gravity. The same acceleration will be given by any one of the combinations in the accompanying table.

Period, sec.	Amplitude, in.
0.500	1.000
0.250	0.250
0.125	0.062
2.000	16.000

The oscillation in the first line of the table will give the passenger a push equal to two-fifths of his weight twice in each second; that in the second line will give him the same push four times in each second. If one faces a sparring partner, does it not matter how often one is hit as well as how hard? It follows that the first vibration will be less disagreeable than the second, even though the accelerations are the same. Furthermore, an oscillation of a 2-sec. period and a 16-in. amplitude would

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cause a different type of discomfort. But such large slow oscillations never occur in automobiles; they belong in the sphere of naval architecture.

Evidently the physiological effect of acceleration cannot be separated from frequency. No quantitative relations can be given at present, but in analyzing seismograms the fact should be borne in mind that, in general, the higher the frequency with which a given acceleration is repeated the harder the riding will seem.

It is sometimes argued that, since the rate of change of acceleration is of great importance in fore-and-aft acceleration, as in the starting and stopping of trains and street cars, the same should be true in up-and-down acceleration. The two questions are wholly unrelated because in starting and stopping street cars, for example, the accelerating and decelerating forces are applied to the passenger below his center of gravity and a rotating or pitching tendency is introduced; the passenger must then adjust his muscles to counterbalance this. Such acceleration must therefore be gradual enough to allow the passenger time for this adjustment, but obviously this does not apply to vertical accelerations.

Although the rate of change of acceleration may be dismissed from a physiological standpoint, it is very important from a physical standpoint. It is not within the scope of this paper to go into this matter further. It need only be pointed out that rate of change of acceleration is directly connected with frame-whipping and body-tremors, which in turn produce local accelerations that affect the passenger.

Turning now to the question of amplitude, it is well understood that the vibrations of an automobile body as a whole are composed of forced vibrations having the period of the road shocks, and free oscillations having the natural period of the suspended body itself. The amplitude of the forced vibrations is in itself of little importance; it is the acceleration that counts.

But amplitude is of more importance in the free oscillation, because a large amplitude affects not only the sensation of stability, but stability itself. Thus, when the rear end of the body is on the high point of a large swing, the pressure between the tires and the road is diminished, with consequent decrease in the directive and tractive forces. Moreover, since the oscillations of an automobile body consist of vertical motions of the center of gravity and rotary motions about it, vertical ampli-

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tude is a measure of rotary amplitude and hence of rotary acceleration. In short-wheelbase cars these rotary accelerations sometimes administer disagreeable shoves from behind, near the shoulder-blades. This point should be kept in mind when interpreting seismograms.

While mentioning the subject of wheelbase, it might be well to point out the fallacy of certain notions which have gained currency, such as that the body periods can be lengthened by turning cantilever springs inside out, so to speak, or by sloping cross-springs away from the body center and thereby lengthening the distance between front and rear-spring anchorages on the frame. This matter can be settled by recourse to the simplest basic principles that for every action there is an equal and opposite reaction, as stated in the third law of motion. This means that the line of action of a force remains unchanged if the shape of the mechanical connections be altered. Thus, every designer knows that the line of action of the force between the wrist-pin and crank-pin is a straight line joining their centers; and no matter what shape or bends the connecting-rod may have, the line of action of the force is unchanged. Applying this principle to springs, we see that if the path of the wheel, with reference to the body, as it moves toward the body, is substantially a straight line perpendicular to the axis of the body, as is always the case, then the line of action of the force exerted by the spring on the wheel, which equals the reaction on the body, is substantially a perpendicular line through the wheel center. This is true no matter what form the spring takes. Likewise, the magnitude of this spring force is the product of its rate and its deflection, irrespective of the shape of the spring. It follows that the body periods are completely determined by the spring rates, the mass and radius of gyration of the body and the actual wheelbase, and it does not matter what shape the springs themselves may take.

It does not necessarily follow that such peculiar dispositions of springs will not produce better riding qualities. Thus they may permit the use of more spring material, resulting in a more flexible spring. The binding actions at the shackles, on the other hand, may result in an additional shock-absorber effect, which would have an appreciable influence on the riding qualities and an equally appreciable influence on the life of the shackle, but the shape of the spring itself has no effect.

Turning to damping, which is directly related to fric-

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tion, its function is well understood. It limits the amplitude of the free oscillations, whether due to a single impact or to accidental resonance between road bumps and body periods. In general, the greater the damping the smaller will be the amplitude of the free oscillations, however caused, and the more rapidly will they die out.

However introduced, friction always increases the forced oscillations. The seismograph enables us to determine experimentally how much friction to add to the springs to secure the desired damping and what increase in the forced vibrations this added friction causes.

Damping can be conveniently determined by driving the car over a larger bump, at a desired speed, and noting from the seismogram the number of swings the body performs in coming approximately to rest. The car can also be driven at a critical speed over a certain road and the amplitude of the free oscillations determined from the seismograms.

Summarizing, the most important factors that determine riding qualities are: The vertical accelerations, both forced and free; the frequency with which they are repeated; the amplitude of the free oscillations; the damping of the free oscillations; and rotary acceleration. All of these, except the last, can be directly determined by the seismograph.

Preliminary Experimental Results

I hope to give later a detailed account of the experimental investigation of riding qualities now under way, but I can say now that the results have definitely shown the riding qualities of a given car to vary to an extent not realized by most engineers. Thus, measurements on several trucks of a large fleet operating in New York City showed that, on a certain stretch of upper Fifth Avenue a maximum vertical acceleration of approximately one-half that due to gravity was developed on new trucks; but on trucks that had been a year or more in service the corresponding acceleration was about one and one-half times that due to gravity, a difference of some 300 per cent. A later test showed that most of this change occurred between the third and the twelfth day of service, in that one instance. The general results of the tests on the trucks of this fleet may be expressed thus: When new, they ride like touring cars, but after some length of service they ride like trucks.

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In conclusion I wish to ask the question: What is the difference in the behavior of steel undergoing a cyclic repetition of stress, as compared with an acyclic repetition? Fatigue tests are always made under cyclic conditions. Many investigators have noted, however, that at the beginning of such tests there is a transient or "settling-down" stage in which the specimen "gets its stride." So far as I know, only one man, Dr. W. Mason,[a] has investigated the effect of change of speed in a fatigue test. He found that when a fatigue test-specimen had become "trained" to a slow cycle of torsional stress, the cyclic strains following a more rapid repetition of the same stress were temporarily reduced, and vice versa. Dr. Mason worked with stresses, frequencies and conditions far different from those existing in automobile springs, but in a general way his results are in entire accord with my own observation that the greatest enemy of good riding is spring-fatigue.

A wide field for research is opened by acyclic fatigue tests, which should be of great interest to the members of this Society and to all those interested in the testing of metals. Not only would such tests add greatly to our knowledge of metals, but, if I may venture a prophecy, the acyclic method of testing would greatly shorten the time required for fatigue tests and so attain a long-sought goal.

Appendix I

Suppose a weight, of mass M (See Fig. 8), is hung by a spring of stiffness K, from a point of support that is undergoing a simple harmonic motion of amplitude E and period T_1. Let x be the displacement at any instant of the point of support from its neutral position, and let y be the corresponding instantaneous displacement of the mass. Also, let the static deflection of the mass be δ; in other words, the weight Mg stretches this spring an amount δ.

The force acting upward on the mass is the stretch of the spring times its stiffness. The spring-stretch is obviously the difference in the displacements x and y, plus the static deflection $(x - y + \delta)$. The force acting downward is the weight, Mg. Let us call upward forces positive; then by equating the algebraic sum to mass times acceleration we get

[a] See *Proceedings* of Royal Society of London, vol. 92.

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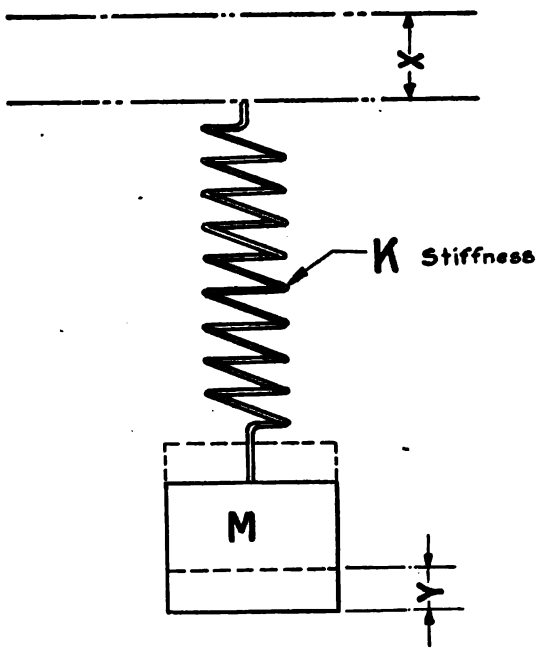

FIG. 8—ANALYSIS OF SPRING ACTION

$$M\frac{d^2y}{dt^2} = -Mg + K(x - y + \delta)$$

But since δ is the spring-stretch due to the weight acting alone

$$Mg = K\delta, \text{ hence}$$

$$M\frac{d^2y}{dt^2} = Kx - Ky, \text{ or}$$

$$M\frac{d^2y}{dt^2} + Ky = Kx \qquad (1)$$

The simple harmonic motion of the point of support is expressed by

$$x = E \sin\left(\frac{2\pi}{T_1}\right)t \qquad (2)$$

For abbreviation, put

$$\frac{2\pi}{T_1} = p \text{ or } T_1 = \frac{2\pi}{p} \qquad (3)$$

p is called the "frequency-speed" and is equal to 2π times frequency.

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Substituting in equation (1), we obtain

$$M\frac{d^2y}{dt^2}+Ky=KE\sin pt \qquad (4)$$

This is a familiar differential equation whose general solution is given in all textbooks on the subject. Suffice it to say, that the general solution consists of two parts

$$Y_1=A\sin qt+B\cos qt \text{ (Free oscillation)} \qquad (5)$$
$$Y_2=C\sin pt+D\cos pt \text{ (Forced oscillation)} \qquad (6)$$

The constants A, B, C, D, are obtained by substitution in equation (4), and from the initial conditions, that the weight is at rest when the motions start. Mathematically specified, the initial conditions are that when

$$t=0, y=0, \frac{dy}{dt}=0$$

Substituting equation (6) in equation (4), we obtain

$$p^2M(C\sin pt+D\cos pt)+K(C\sin pt+D\cos pt)=KE\sin pt$$

This is true for all values of t; so put $t=0$, which makes

$$\sin pt=0, \cos pt=1, \text{ and we get}$$
$$(-p^2M+K)D=0 \quad \therefore D=0 \text{ and hence we get}$$
$$(-p^2M+K)C\sin pt=KE\sin pt, \text{ hence}$$
$$C=\frac{KE}{p^2M-K} \text{ (Amplitude of forced vibration)} \qquad (7)$$

This is the amplitude of the forced vibration. The period of the forced vibration is the same as the period of oscillation of the point of support. Hence the forced vibration period is given by the equation

$$Y_2=\frac{KE}{p^2M-K}\sin pt \quad \text{(Forced vibration)} \qquad (8)$$

Referring now to the equation of free oscillation (5), the quantity q is related to the period T_1 of free oscillation by the following equation which is similar to equation (3):

$$q=\frac{2\pi}{T_1} \text{ or } T_1=\frac{2\pi}{q} \qquad (9)$$

As is well known, or, as can be shown by substituting equation (5) in the left-hand side of equation (4) and equating to zero, the period of free oscillation is given by

$$T_1=2\pi\sqrt{\frac{M}{K}} \quad \text{or } T_1=2\pi\sqrt{\frac{\delta}{g}} \qquad (10)$$

To determine the constants A and B, we must remem-

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ber that the whole motion of M is given by the sum of equations (5) and (6). Remembering also that determining the constants C and D makes equation (6) reduce to equation (8), we have

$$Y = Y_1 + Y_2 = \frac{KE}{K - p^2M} \sin pt + A \sin qt + B \cos qt$$

Diffcrentiating

$$\frac{dy}{dt} = \frac{pKE}{K - p^2M} \cos pt + qA \cos qt - qB \sin qt$$

Introducing our initial conditions

$$y = 0, \frac{dy}{dt} = 0, \text{ when } t = 0$$

$$0 = 0 + 0 + B, \text{ hence } B = 0$$

$$0 = \frac{pKE}{K - p^2M} + qA, \text{ hence}$$

$$A = -\frac{p}{q} \frac{KE}{K - p^2M} \qquad (11)$$

This is the amplitude of the free oscillation. Hence, the expression in equation (5) for the free oscillation becomes

$$y = -\frac{p}{q} \frac{KE}{K - p^2M} \sin qt \quad \text{(Free oscillation)} \qquad (12)$$

Summarizing, we may say that: If the point of support undergoes a simple harmonic motion of amplitude E and period T_1, the weight will undergo two simple harmonic motions, one of which, called the forced oscillation, will have the same period T_1, and amplitude $\frac{KE}{K - p^2M}$; the other of which, called the free oscillation, $T_2 = 2\pi$ will have the period $\sqrt{\frac{M}{K}}$.

and the amplitude $-\frac{pKE}{q(K - p^2M)}$

The negative sign indicates that the free and forced oscillations are opposite in phase.

The expression for the amplitudes can be simplified, as follows:

$$\frac{K}{K - p^2M} = \frac{\frac{K}{M}}{\frac{K}{M} - p^2}, \text{ but}$$

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$$p = \frac{2\pi}{T_1}, \text{ or } p^2 = \frac{4\pi^2}{T_1^2}, \text{ and}$$

$$T_2 = 2\pi\sqrt{\frac{M}{K}}, \text{ hence } \frac{K}{M} = \frac{4\pi^2}{T_2^2}, \text{ hence}$$

$$\frac{K}{K - p^2M} = \frac{\frac{4\pi^2}{T_2^2}}{\frac{4\pi^2}{T_2^2} - \frac{4\pi^2}{T_1^2}} = \frac{\frac{1}{T_2^2}}{\frac{1}{T_2^2} - \frac{1}{T_1^2}}$$

Multiplying the numerator and the denominator by $T_1^2 T_2^2$, we get

$$\frac{K}{K - p^2M} = \frac{T_1^2}{T_1^2 - T_2^2}$$

In the same way

$$\frac{p}{q} = \frac{T_2}{T_1}, \text{ and}$$

$$\frac{p}{q}\frac{K}{K - p^2M} = \frac{T_2}{T_1} \times \frac{T_1^2}{T_1^2 - T_2^2}$$

Hence, our amplitudes become

$$\frac{T_1^2}{T_1^2 - T_2^2} \times E \text{ (Forced oscillation), and}$$

$$\frac{T_2}{T_1} \times \frac{T_1^2}{T_1^2 - T_2^2} \times E \text{ (Free oscillation)}$$

We shall now make use of the practical fact that, if such a system is to be useful for seismographic purposes, the period of free oscillation must be large compared with any period of forced oscillation which we are likely to meet, i.e., T_2 is large compared with T_1. Hence it gives a good approximation to neglect T_1^2 compared with T_2^2, and we get for our amplitudes

$$\frac{T_1^2}{T_2^2} \times E \text{ (Forced oscillation)}$$

$$\frac{T_1}{T_2} \times E \text{ (Free oscillation)}$$

The negative sign has been omitted, as it merely indicates phase relations.

Hence, we may say that the ratio of the amplitude of the *forced* oscillation to the amplitude E of the *forcing* oscillation equals the *square* of the ratio of the *forced period* to the *free period;* and the ratio of amplitude of the *free* oscillation to the amplitude of the *forcing* oscillation equals the ratio of the *forced period* to the *free period.*

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In this part of the analysis we have neglected friction. We shall consider first the forced oscillation, as this is the one that causes a real instrumental error. The free oscillation, as will be shown, amounts to nothing more than a slowly-wandering zero.

From the above, it follows that, to keep down the forced oscillation and hence make the instrumental error small, the free period of the inertia element must be long when compared with the longest period of vibration of the vehicle body.

For, on account of the axle motion, the vehicle body itself undergoes forced and free vibrations and both of these are *forcing* vibrations from the standpoint of the inertia element. The longest free period of the vehicle body is the longest *forced* period on the inertia element which need be considered in practice; hence we may state as the fundamental requirement that

> The free period of the seismograph must be long compared with the free periods of the vehicle body. Or, since the periods are functions of the deflections, the static deflection of the seismograph spring must be very large compared with the static deflections of the vehicle springs

Let us consider a practical example. Suppose a point in the vehicle body is oscillating with an amplitude of 1 in. and a period of ½ sec.; and suppose the period of the inertia element of the seismograph is 2½ sec. Then the ratio of periods is 1 to 5, and the amplitude of the forced vibration of the inertia element will be $1 \times (\frac{1}{5})^2 = \frac{1}{25}$ in. In other words, if the period of the seismograph is five times that of the vehicle body, the forced oscillation of the inertia element will have one-twenty-fifth of the amplitude of the free motion of the vehicle body. The greatest instrumental error would, therefore, be 4 per cent. This accuracy is entirely satisfactory for all practical purposes. We may, therefore, say that the free period of the seismograph should be about five times the longest free period of the vehicle body.

The free periods we meet with in automobiles may reach perhaps 0.7 sec. or more; hence a seismograph for motor vehicles should have a period of about 3½ sec. or longer.

Turning now to the free oscillation, we find that its amplitude is to that of the forcing oscillation inversely as the ratio of periods; so that, if the ratio of periods

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is 1 to 5, and the amplitude of the body-motion is 1 in., the free amplitude of the weight-motion will be 0.2 in.

To see the effect this has on the curve, suppose the zero to be stationary, and the body to be executing a free oscillation such as is shown in Fig. 9 by the light full line *C*. The corresponding free motion of the weight is indicated by the line *W*, and the resulting distortion of the record by the heavy line *V*.

No extended analysis is necessary to show that, when the period of the weight is long compared with that of the impressed oscillations, 5 to 1 for example, the record distortion caused by the free oscillations of the weight produces no appreciable error in acceleration, amplitude or damping. Of course, the free oscillations of the weight are damped. In the figure we have assumed them to be undamped to exhibit the worst case.

In any case, it is impossible to design an inertia-operated seismograph so that the weight will remain absolutely at rest. To emphasize this point, imagine that a sudden change occurs in the road-level (Fig. 10). As the various body-oscillations resulting from the impact die out, the inertia element, if perfectly damped, will gradually move to its new zero-position in space, which is its old zero-position with reference to the car. During the transition, the zero-position of the weight will therefore shift gradually. A wandering zero is therefore inherent in such devices. The wandering zero occurs in many types of instruments. A notable example is the syphon recorder used as a receiver in submarine cable work.

In the above analysis we have considered the vehicle body as performing one simple harmonic oscillation, whereas the actual motion is a very complicated, irregular curve. But no matter how irregular, any particular portion of the curve can be represented by a series of simple harmonic motions, called a Fourier's series. Each term of this series will give rise to a corresponding term in each of two similar series representing the forced and free motions of the seismograph weight respectively. The relations found above for a single simple harmonic oscillation will hold for each term of the series. The longest period in the series which is of importance from a practical standpoint, is the period of free oscillation of the vehicle body; and if the instrumental error is small for this term, it will be still smaller for the shorter periods.

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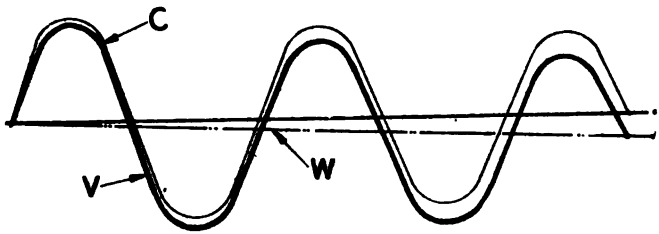

FIG. 9—EFFECT OF THE FREE MOTION OF A WEIGHT UPON A BODY EXECUTING A FREE OSCILLATION

APPENDIX II.

Referring to Fig. 2, imagine a pivoted rod, whose arms are a and b inches long, to have a spring fastened at one end and a load, f, applied at the other. Let k be the stiffness of the spring, and r the spring reaction or pull. When the system is in equilibrium, as indicated by the full lines

$$ra = fb.$$

Also, if the spring has been stretched a distance s to balance f, then

$$r = ks, \text{ and}$$
$$ksa = fb.$$

Let the force f be now increased a little to become $f + \Delta f$; then the system will move to a new equilibrium-position, shown by the dotted line. Note that the force f has moved through a distance d, while the spring has received an additional stretch c, the relation between c and d being obviously

$$\frac{c}{d} = \frac{a}{b} \text{ or } c = \frac{a}{b} d$$

The new spring reaction is r', for instance, where

$$r' = r + \Delta r = (s + c)k = r + ck$$

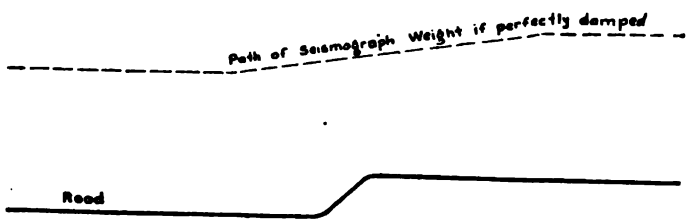

FIG. 10—EFFECT OF A CHANGE IN ROAD LEVEL UPON THE SEISMOGRAPH WEIGHT

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Taking moments about the point of support, we have

$$(r + ck)a = (f + \Delta f)b, \text{ hence}$$
$$cka = \Delta fb \text{ (For } ra = fb\text{), hence}$$
$$\Delta f = \frac{a}{b}\, ck = \left(\frac{a}{b}\right)^2 dk$$

To find the stiffness, or rate, of a spring, we divide the load by the deflection, or the increment in load by the corresponding increment of deflection. The combination of lever and spring acts as a simple spring whose stiffness is such that when the load is increased by Δf, the deflection increment is d. Hence, the stiffness of the lever suspension is

$$\frac{\Delta f}{d} = \left(\frac{a}{b}\right)^2 k = k \div \left(\frac{b}{a}\right)^2$$

Hence, we obtain

Theorem I: The stiffness of the lever suspension is equal to the stiffness of its spring divided by the square of the lever-arm ratio

The static deflection of a spring is the load divided by the stiffness or $\frac{r}{k}$. If the spring of the suspension can carry a load $f\,r$, then at the long end of the lever it can carry only $\frac{a}{b}\, r$. The *static deflection* δ of the lever suspension is, therefore

$$\delta = \frac{a}{b} \cdot r \div \left(\frac{a}{b}\right)^2 k = \frac{r}{k} \cdot \frac{b}{a}$$

But $\frac{r}{k}$ is the static deflection of the coil spring k under a load r, which we denoted above by s. Hence, the static deflection of the lever suspension is given by

$$\delta = s\, \frac{b}{a}$$

We therefore obtain

Theorem II: The lever suspension multiplies the static deflection of its spring by the lever-arm ratio

THE DISCUSSION

H. M. BROWN:—We are all aiming toward the same thing, of course, and we all get different results. I de-

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vised an instrument to do in a much cruder way what Dr. Liebowitz has described. I obtained the little wiggles he mentioned, finding that it did not require a new car to get them. We could get very decided wiggles with an old car. If the springs are lubricated, wiggles almost disappear. When the springs are old, if a reasonable amount of the excessive friction between the leaves is eliminated, a smooth riding car results.

R. W. A. BREWER:—Reference was made to a proposed method of producing a diagram on a fence from the side of the car. Before leaving England, I saw some very interesting photographs that were taken by night on Brooklands track. The car had several lamps attached in various vertical positions on its side and a series of lamps on two wheels. Photographs were then made as the car went over an obstacle on the track. These various photographs gave, of course, exact permanent records of the vertical heights of the various parts of the machine, under different conditions. This is a very simple method of obtaining results when one is investigating spring problems.

B. F. TILLSON:—I would like to raise a question in regard to the differentiation between wheelbase and springbase. Is the contention in regard to a long springbase of merit? Casually, it might seem correct to assume that the point of attachment of the spring to the car definitely affects the displacement, or the amplitude of motion of the car in a vertical plane. If that is responsible for the discomfort of the passenger, it would then seem that an elliptic or a semi-elliptic spring, where there are two points of attachment for one spring and whose effective point of attachment to the chassis would seem to be the mean distance between those two points of attachment, would be at an extreme disadvantage, as compared with the cantilever type of spring, whose single point of attachment might be at the remotest distance, or at the extremity of the car, away from the axle. If, however, the acceleration is the chief function of discomfort, it might seem that that point is poorly taken, and that the difference between the length of wheelbase and springbase would not be of great moment.

A MEMBER:—I think that if the springs are made long enough, wide enough and thin enough, all the present wiggles, jounces and troubles will be avoided. The principal trouble in automobile springs is through a limitation of construction designs. Springs are made deep and

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short. All the levers and auxiliary springs used are to dodge this question of having the springs long, wide and thin. Reference was made to the old-style coach. I have had some experiences in the carriage trade and call the attention of automotive engineers to carriage springs. The springs of the easier-riding carriages, like the coaches, or of the heavier ones, were much longer, being several times longer in proportion to the load carried, than anything we have in the automobile today. The other point is that the spring should not do anything more than act as a spring. To make a torsion or a thrust-rod out of a spring, introduces some wiggles and produces stress of materials and spring fatigue.

O. A. MALYCHEVITCH:—Some years ago I was connected with a factory in England which is engaged in building all the omnibuses for the London General Omnibus Co. An investigation was made of the question just discussed on the basis of a series of articles printed in one of the best automobile publications in France.[4] The result showed that the front axle and frame have their own vibration, i.e., their own average amplitude and length of wave or period of vibration. The method applied was similar to the one just mentioned. Lights were fixed on the front and back axles, frame and body of an omnibus, which passed before the camera at different speeds on different kinds of road with and without obstacles. The result corresponded to that described in the articles mentioned and also showed that with an omnibus having solid tires, when traveling over an obstacle, the amplitude of vibration and vertical speed of the frame and body grow enormously with increase of speed, while the front axle varies but little. The period of vibration or length of wave of the frame and axle increases if the load and speed increase, and by varying the position of the load or passengers different combinations and coincidences of the wave of vibration can be obtained. With pneumatic tires the result will be altogether different. Therefore, any problem concerning the measurement of vehicle vibration should be considered very carefully, on account of these differences in vibration of each principal part of the chassis or each principal wave which may occur in a solid-tired omnibus having a constantly varied load.

[4] *La Technique Automobile et Aerienne*, 1914. Les Pertes par Roulement des Automobiles.

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R. A. SCHAAF:—W. C. Keys[5] brought the method of measuring the performance of springs by means of lights to our attention at a meeting of the Pennsylvania Section of the Society about two years ago. In the experiments he described there was one light on the axle, one on the passenger's hat and another on the body of the car. The relative motion of all three was shown very effectively. As a previous speaker said, it is not a question of the vibration of the passenger, car or axle, but of the relative motion of all three with respect to each other.

Another speaker said that ease of riding is altogether a matter of spring length. In the old horse-drawn vehicle days the length of a spring compared with the load it carried was very much greater than in the modern automobile. I agree that if the spring is long enough and its leaves thin enough all the little wiggles we have heard so much about will disappear.

As spring-makers we are not in the habit of talking about periodicity or amplitude or any of the other related terms. Instead we always speak of the deflection or travel of a spring. I do not know exactly what relation exists between travel and amplitude and periodicity, but I do know that the travel of a spring affords a very simple method of comparing the riding quality of one spring with that of another. For instance, if one spring has a travel of 4 in. and another a travel of 5 in., other things being the same, the spring with the 5-in. travel will ride better than that with 4-in. By "travel" is meant the difference between the height of the spring as it lies on the floor and its height under the loaded car. It is the distance it "travels" or deflects when its full load is applied.

G. R. PENNINGTON:—I may be mistaken in this but I understand that to get a long period it is the main object of a designer to soften out the bumps if the period is long. This period varies inversely as the square root of the pounds per inch deflection. Therefore, the pounds per inch should be small if the period is to be long and if the car is to ride smoothly. If the number of pounds per inch is small, we should have a great deflection in a given bump. We are limited in that, in passenger-car designs, by the construction of the frame and by the amount of movement that we permit the passenger to have. That is the real limitation as I see it. The whole thing starts from the total amount of movement the body

[5] S. A. E. TRANSACTIONS, vol. 12, part 2, p. 454.

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can be permitted to have. Given this, we want the softest spring; having obtained such a spring, we can hardly go any further in other variations because all conditions have then been established.

A MEMBER:—In the past year I have had the questionable pleasure of driving five of the cheaper grades of car. They all had different styles of spring suspension. Aside from the mathematics of the proposition, what contributed more to ease of riding in my experience was the direction in which the spring allowed the axles to deflect when a bump was struck; in other words, I was interested as to the length of time it took the axle to move relative to the body, and in what direction it moved. That has not been mentioned. It is my experience that the full elliptic springs give better results than any of the other methods of springing.

F. C. MOCK:—As one of the previous speakers said, a good basis for analysis of spring action is the deflection of the spring when its normal load is placed upon it. Suppose we have two springs, one of which deflects 5 in. when its normal load is placed upon it, which is about the deflection used on the rear springs of the higher-grade cars, and another which goes down but 2½ in., this being typical of a very stiff spring suspension. Assume that the cars carrying these springs in turn strike a bump 3 in. high, at such a speed that the first-mentioned spring deflects 2 in. This leaves 1 in. of the bump, less the tire and seat-cushion action, which the passengers will receive. If the second spring, half as flexible, takes the same bump at the same speed, the spring will deflect about half as much, or 1 in., leaving 2 in. of bump for the tires, seat cushions and passengers to absorb. Thus, absorption of road shocks increases with a high initial deflection of the spring and requires room for considerable travel between the wheel and axle system and the body. The early coaches just mentioned always had 8 in. or more of clearance between running gear and body.

Often important to the purchasing agent, there is a physical law that for a given load and given fiber stress the weight of material in springs must be proportional to their deflection. As we buy our springs on a price per pound basis, the 5-in.-deflection spring just mentioned would cost at least twice as much as the 2½-in. This is why the springs of higher deflection are found on the high-priced cars.

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Another point of comparison, not always to the advantage of the large-deflection spring, is the force and distance of reaction. A spring tends, in general, to give back in throw just as much energy as is represented in its deflection. In the preceding illustration, after the 5-in.-deflection spring has reached the top of the bump, it will tend to throw back 2 in. to reach a condition of normal stress, and may continue 1¾ in. beyond that; a total throw of 3¾ in. The 2½-in.-deflection spring will have about 1¾-in. throw, but this will take place in less time, so that acceleration for some of the passengers may be of equal or greater violence. In practice this rebound action seems to constitute the limit on the flexibility of springs that we can use on automobiles. It seems that there is a certain amount of throw that can be tolerated, possibly depending upon the ratio of sprung to unsprung weight. Inasmuch as the stiffness of the spring for a given deflection on a given bump must increase as the square of the speed, to hold the deflection and resulting throw within reasonable limits on racing cars, requires very stiff springs.

In dropping into holes, the more flexible spring has the advantage. Let us assume that the car of our previous illustration reaches a depression in the road 2½ in. deep. If the wheel of the 2½-in.-deflection spring should reach the bottom of the hole before the body falls very far, the spring will be practically free, that is, exerting no support upon the body and the body will fall with the acceleration of gravity into the hole. If we assume that with the 5-in.-deflection spring the wheel reaches the bottom of the hole before the body has fallen perceptibly, the spring will still be under 2½-in. compression, will be exerting one-half of its normal sustentation against the body, and the body will tend to fall into the hole only half as fast. In other words, when you see a car pass over a choppy road with the body steady but the wheels jumping up and down rapidly, the springs of that car are relatively flexible. With stiff springs the car will ride much more roughly.

As to the matter of balance, most studies in spring action are confined to the action of the front or rear springs individually, whereas their relative action has a prominent effect as regards ease of riding. When you impart a shock to one end of a body whose mass is distributed throughout its length, as in Fig. 11, it takes up a motion of translation and of rotation, with the result that the

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other end actually moves toward the shock. In an automobile, as you will find upon observation, when the front end rises on a bump the rear end goes down, and the amount of this drop often determines the force of the subsequent shock of this same bump on the rear passengers. This action is a function of the weight distribution, as will be evident from the middle and bottom portions of the accompanying drawing. Note the travel of the points *a* and *b*, at which the passengers are usually located. The arrangement in the middle gives the easiest riding at the point *a*, and would be a weight distribution suitable for a roadster. That at the bottom would give much better riding qualities in the rear seat and almost as good in the front seat, but will be more apt to skid rounding corners, of course. The difference in riding with these different weight distributions is easily demonstrated by towing a chassis with a weighted load which can be shifted to different points.

Another point in the interrelation of the front and rear springs is their periodicity. If you try to "teeter" the front or rear end of an automobile, which can be done if there are no shock absorbers, it will be found that each pair of springs tends to oscillate at a definite rate which will correspond pretty closely with the formula already mentioned,

$$\text{Time of one oscillation} = 2\,\pi\sqrt{\frac{\text{initial deflection}}{32.2}}$$

Purely as a matter of interest, I have made it a point to observe the periodicity of different cars I have encountered with exceptional riding qualities, either good or bad. What we know as a stiff spring will have a frequency of 140 to 180 vibrations per min. What is generally known as a long slow spring will have a frequency of about 90 vibrations per min. It is noticeable that when the periodicity of the front and of the rear springs is approximately equal, the car has a very strong tendency to pitch and to take up a rocking motion when going along the road. The best riding cars seem to have a frequency of between 85 and 100 vibrations per min. on the rear springs and all the way from 120 to 160 vibrations per min. on the front springs. Provided the unsprung weight is not too high, the spring action is retained within bounds by bumpers and recoil checks and the load distribution is reasonably good, I believe that 120 to 130 vibrations per min. of the front spring (this

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is a fairly soft front spring and it is necessary that the steering length be laid out so that the motion of the front springs does not steer the car from side to side) and 85 to 90 vibrations per min. under full load for the rear spring, will give the best riding qualities over an average of all conditions of use.

F. JEHLE:—I am wondering whether the relation between sprung and unsprung weight has been given all the consideration it deserves in this spring problem. It

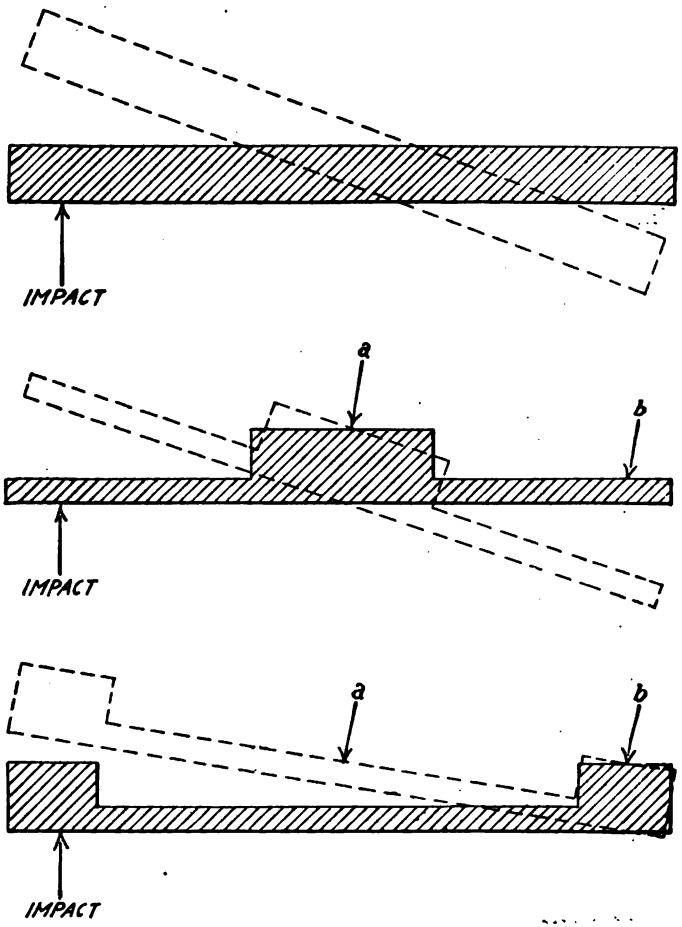

FIG. 11—EFFECT OF IMPARTING A SHOCK TO ONE END OF A BODY WHOSE MASS IS DISTRIBUTED THROUGHOUT ITS LENGTH

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seems to me that the wheel can be considered as a cam follower. The flat surface of the road is the base circle of the cam action, and the bump in it is the cam. With a given weight to accelerate, which is the unsprung weight, we must put on top of that a certain weight to hold it down, to make it follow the road. That force will be represented, I believe, by the sprung weight of the car. I do not wish to return to the acceleration problem but, neglecting the portion of the energy absorbed by the rubber tire, which of course is wrong, I am inclined to agree with Mr. Favary that the acceleration forces are extremely high. If this has been worked out for a certain unsprung weight, is there a definite sprung weight which is correct? Having determined that, the problem of the spring-maker would be to make a spring to go in between the two pieces, and be flexible enough to take care of the bumps.

H. M. CRANE:—Several of the speakers have brought into the discussion an element that has not been sufficiently considered, the longitudinal shocks caused in a chassis by meeting obstructions on the road. Recalling Mr. Favary's sketch in which he figured the change in velocity of the rear axle, we must realize that, to change that velocity, not only would a vertical component be required, but also a horizontal component working with it. In other words, if we have a car in which the axle is attached to the chassis with no spring whatever in a horizontal direction, where there is no spring in any of the parts, none at the tire, and none in the bump that is hit, it would be impossible for the car to proceed beyond that bump until the axle had surmounted it. I think that any figures as to the shocks that would occur under those conditions would be astounding.

Of course, like many other things on the road, we leave it to the tires to take care of that element, or we have left it so to a large extent. But from time to time there have been spring arrangements, like the full elliptic spring or the front semi-elliptic set at a slope in which the axle is allowed to recede on rising, that have helped to a certain extent. But none of them has helped as much as would some arrangement allowing the axle to move against spring pressure, not in a vertical line but in a line rising toward the rear, and not as in most cases on an arc of a circle swinging around a pivot. The full elliptic spring, due to its height and the possibility of bending under, has in a way provided this condition. There

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is still a third point, the lateral vibrations which have been too little considered and which again a full elliptic spring has helped a great deal. The car proceeding down the road encounters unequal obstructions on the two sides; the axle is forced to take positions angular to the body center, instead of parallel with it. In practically all spring suspension, the attempt to take those positions results in side-thrusts in the chassis frame, which may become very severe. The full elliptic spring, as can readily be seen, being 8 to 10 in. high from the point of support on the axle to the point of support on the frame, and being relatively weak sideways due to the narrow leaves, gives an excellent cushion for this type of shock. The prevailing type of flat semi-elliptic spring with wide leaves is about the worst kind of construction that we can use in this regard. Unless something is done in the method of attaching the spring to the chassis frame, we will develop an entirely new kind of vibration that is far from comfortable. If Dr. Liebowitz can add some elements to his apparatus to take in these other vibrations, he will have made further progress.

E. FAVARY:—To answer the remarks of Mr. Crane it is very important to consider the horizontal motion of the axle when it is impelled upward. I believe I have mentioned that in my paper, and shown that the acceleration can be reduced, if means are permitted to allow the axle to move backward. In practice, as Mr. Crane mentioned, one method is to slope the spring, have the front spring-eyes higher than the rear. Another method would be to attach the front eye rigidly and shackle the rear end; this would permit a slight backward motion of the axle, when the clearance between the latter and the body is decreased.

DR. H. C. DICKINSON:—It seems unfortunate that a problem which is essentially so simple should be apparently so very complex. There are two elementary functions to be performed by the spring suspension. The springs separate a rear axle and wheel system from the body. It is important that the wheels remain on the ground as much as possible. They must, therefore, follow the irregularities of the road and to do this the period of vibration of the wheel referred to the body should be as rapid as possible. On the other hand, the body is required to have the least possible vertical motion; its period of vibration with reference to the wheels on the ground should be as slow as possible. This means the

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lightest possible axle and wheel system to respond quickly to road irregularities and the longest practicable initial deflection of the springs to give the body as slow a period as possible. It seems to me that Dr. Liebowitz has designed an ideal spring suspension. This supports the contention that really the fundamental thing is to have a considerable deflection of the springs to start with.

There is another point, however, which I believe is worthy of some discussion. Dr. Liebowitz has brought up a contention which, if sustained, is such an absolutely fundamental contradiction of all that we know about elastic bodies that I would like to hear further opinion on the subject. We have studied springs, as he says, for the last several hundred years, and know something about elastic hysteresis and so forth. Now elastic hysteresis exists and springs do change their characteristics after repeated stress, but the changes so far as we know are extremely small and it seems to me that he requires for the action which he has stated a sudden change, that is, a broken, irregular change in the resilience of the spring amounting to about 100 per cent of its original stiffness. If that is the case, it is absolutely contrary to our experience, because the changes in all these experiments which he has cited are usually of the order of a few parts in ten thousand, and none of them much greater, I believe. Moreover, springs are used for various purposes. For instance, the spring is used as a torsion suspension where the force is determined by the torsion of a spring wire and such suspensions are used at various amplitudes and in various ways. These things have been experimented upon for many years and found to give very consistent results, and no irregularities in their action resembling those shown by Dr. Liebowitz have ever been discovered so far as I know. Their restoring force has changed somewhat in some cases, but always in a smooth curve, not an irregular one. This same thing is true of weighing mechanisms which involve very stiff springs under very heavy initial load, and in a great many other cases which I could cite, where the action of springs under both repeated stress and otherwise has been determined. We use them in our watches for hairsprings and the action of the steel is under repeated stress, even under stresses which are not very small. The behavior of these springs is always very consistent when we consider magnitudes of several per cent. In fact the consistency of the hairspring of a watch is a remarkable example of

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exact repetition of behavior which is hard to duplicate.

MR. SCHAFF:—I fully agree with Dr. Dickinson in regard to this phenomenon of spring fatigue after a short period. I think we should be careful about going on record as to any phenomenon of that kind. As far as I know, it takes a long period of constant use to fatigue steel. It is a more complex question than one of short use and complete recovery afterward.

J. S. MACGREGOR:—The question of fatigue for gradual fracture of metals subjected to alternate stresses as well as the question of their hysteresis is always of great interest to automotive engineers. A few years ago I conducted a number of experiments upon several steel bars. These bars had never been subjected to stress previous to tests, other than stresses which result from normal handling subsequent to fabrication. The testing procedure was as follows: A gage length was laid off, the bar subjected to a load well within the elastic limit and the elongation read. The load was then released, the set read and the rate of recovery observed. It was found that, regardless of the time a bar was allowed to rest, recovery to the original gage length was never complete. A new gage length was then laid off and the above cycle or partial cycle repeated; the new set was observed to be less than the first and the rate of recovery although not complete was more rapid. It was observed that the set decreases in magnitude and that the rate of recovery increases with each succeeding cycle, until ultimately the recovery is complete and its rate rapid and practically constant.

These experiments indicate that sound steel becomes more and more truly elastic under repeated stress, the structure apparently becoming oriented or trained to a certain range of load reversal. It would seem, therefore, that a spring should improve in service, if not overloaded, and I am surprised at the author's statement concerning lapses in recovery when repetitions of stress in a spring are rapid and continuous.

W. C. BAKER:—Contrary to Dr. Liebowitz' statement in regard to believing that the elasticity has been reduced, it seems to me it has been increased; that is, it has a greater property of elasticity after it has been continually vibrated.

Reverting to the matter of unsprung load, I believe that the automobile with its rapid speed is an entirely different problem from the ordinary horse-drawn vehicle

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at slow speed. The greatest gain in the riding quality of an automobile can be obtained by reducing the percentage of unsprung load. At high speeds the inertia of the axles and wheels is so great that their amplitude is far beyond the variation due to obstructions in the road. The increased motion is partially imparted to the sprung load, causing extreme bouncing. It is very hard to get springs that will ride easily over cobblestones at slow speeds and at the same time ride well at high speeds, particularly with cars having a low ratio of unsprung load to sprung load. Reducing the unsprung load is our principal problem. The ideal would be unsprung load, zero, no weight whatever. The nearer we approach such a condition, that is, the less the percentage of unsprung load to sprung load, the easier it will be to make an automobile ride well at high speeds.

F. E. MOSKOVICS:—In the Vanderbilt Cup racing days we had a car weighing 2204 lb. Sometimes we had to shave the tires to get down to that weight, but that is what the car weighed. I believe that no cars are raced today over rough tracks like the old Vanderbilt course; there is no modern race course like it. The record Lancia made, up to the time he was wrecked on Long Island, has not yet been approached. His car had, perhaps, the lightest unsprung weight of any car I have ever seen in a race; it had a solid-axle and was chain-driven. In regard to balance, I remember that when the first foreign cars came over, the foreign racing men would place their cars on the scales and weigh them very carefully with the front and the rear ends loaded, including themselves, to get exact balance between the front and the rear end. They watched every relation between the unsprung and the sprung weights. Last year, in California, these things came back to my mind when one of the contestants in the Santa Monica race objected very seriously to the course because there was a bump in the road that raised him up 5 in. when he was going 90 m.p.h. I know that Lancia was going 120 m.p.h. over the rough Vanderbilt course, averaging 79 m.p.h. That was over ten years ago and it was possible simply because he had the best balanced car that ever entered the Vanderbilt Cup races.

MR. TILLSON:—The question was raised as to fatiguing materials, and two diverse views were expressed, which might possibly have been correlated. In the case of the springs considered we are thinking of sudden application and reversal of forces upon metal, a rapid acceleration

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from one state to another state. In the other case, an example might be given to illustrate the remarks of a later speaker who called attention to the fact that springs can be used over long periods of time, involving the consideration of the well-known torsion-pendulum clock in which a mass oscillates around a vertically suspended slight spring. Such a spring undoubtedly makes the reversal of stress many millions of times before it fails by fatigue. I have one of those clocks that has been running for twelve years, and I never had the spring fail from fatigue, but the function of the pendulum is to assume gradually a state of rest and to be stressed gradually in the opposite direction. On the other hand, if we consider the stresses applied in the rock-drilling art, in which pneumatic tools strike a bar of drill steel possibly 1500 times per min., any of the blows of which is far less than the elastic limit of the metal of the drill steel, we find that within a short period of time that steel will fail. The nature of the failure is very certain; the appearance of the fracture will be conchoidal; it will show a growth from a small point of fracture, by gradually expanding layers such as we see in shell, to its final rupture of the entire section of the steel. That is an instance of suddenly applied stresses in a metal which cause, as has been indicated by microscopic examinations, a gradual weakening of the bonds of the molecules of the material. They form initially what is known to the metallurgists as "slip planes." These are planes of fracture through the molecules which are so microscopic as to be lost in general, but can be determined if a specimen is polished prior to being subjected to the stresses.

The same thing was demonstrated six or seven years ago by the investigations of Dr. Dudley into the failure of rails for steam railroads; the pounding of the car wheels on those rails causes them to fail; the fractures are exactly similar to those which I mentioned in regard to drill steel. The fact that we can run a clock spring for years with millions of reversals of stresses does not indicate that we can expect the same service from another spring which is given suddenly applied stresses.

MR. CRANE:—I have ridden in the Knox single-cylinder air-cooled automobile, long ago, which used the old Concord wagon spring, the springs being even more continuous than they were in the Olds curved-dash runabout. In fact, the rigid points of attachment could not have been over 18 in. apart. The action of that car re-

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duced to an absurdity the claim made for the long springbase, because it was a car with possibly a 90-in. wheelbase that had actually a springbase of 18 in. And it was an extremely good riding car, due to the fact that it had unusually soft springs for that day and correspondingly slow movement.

DR. BENJAMIN LIEBOWITZ:—Spring suspensions have always been a prolific source of discussion, and many papers have been written upon the subject. The problem is very evasive, much more so than a casual view of it would indicate. For example, a company which has been using semi-elliptic springs will change to three-quarter elliptic one year, to platform springs the next and then back to semi-elliptics. This summarizes the history of spring experiment and development with many automobile manufacturers. The difficulty is simply that we have hitherto been unable to pin down the exact defect in the present type of suspension. It was a long time before I found out just what this defect is and I suppose it will also take some time before the automotive industry, as a whole, actually realizes it.

We started our work with the assumption that spring steel is imperfectly elastic to a sufficient extent to give hard riding. Our first experiments in the laboratory in 1915 showed that this is not the case when the spring is new. These first experiments showed very clearly, however, that a radical change came over the spring after several hours of hard running in the laboratory, where conditions were much more severe than would be encountered under ordinary road conditions. We did not realize the significance of this result, however, until after our later experiments with trucks.

The claim has often been made that whatever change comes over the springs is due to inter-leaf friction, or friction in the shackles, etc. Quantitative analysis shows, however, that this cannot be the case when the springs have become so imperfectly elastic as to cause accelerations of 1½ times the force of gravity in going over a comparatively small bump. If the spring had functioned with perfect elasticity in this particular case, the acceleration would have been about 30 per cent of the force of gravity; inter-leaf friction, if it were causing the remainder of the acceleration, would have to so stiffen the spring that it would not move until a force equal to 1.2 times the load carried was applied. We know that such magnitudes of inter-leaf friction do not exist, even if a

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spring is rather badly rusted. Ordinarily, the inter-leaf friction may be as high as 20 per cent of the load carried. If we assume the friction to be as high as 20 per cent, then the total acceleration due to friction and to the spring displacement would be ½ of gravity in the case in point. Actually, on a new bus, we did get about ½ of gravity, but on an old bus we got 1½ times gravity. Where did this large additional acceleration come from?

We have been devoting much study to this question and find that the high accelerations are due to the imperfections in the elasticity of the steel, which are brought on by fatigue. Many points that have a bearing on this matter have been brought out in scientific literature. I wish to point out very clearly, however, that this question of fatigue has nothing to do with balance springs or watch springs or springs which are ordinarily used for measuring purposes, because in such cases the stresses are very low and the frequencies are either extremely low, or regular, or both. In the case of vehicle springs, however, we deal with high stresses of a rapid and irregular character. Anyone who has attempted to calibrate a steel spring or bar for purposes of measurement, using high stresses, can testify to the highly irregular character of the results obtained.

I wish to raise one other question at this time, the possible effect of recovery. I have no proof as yet that recovery plays any important part in this matter, but there is some fairly good evidence that it does. It is a very common experience to go out on a day's drive on a fine morning, with the car riding splendidly, but after driving for a number of hours the car seems to ride very hard and the passengers get tired through and through. Of course, we have always attributed this phenomenon to bodily fatigue, but I am not at all sure, in view of some of our more recent experiences, that spring-fatigue may not have something to do with it. Dr. Dickinson spoke of observed changes of the order of tenths of a per cent, or less, in steel's elasticity. Permit me to call attention to the fact that even with the low stresses and low frequencies which Dr. Mason used, he observed changes of the order of 10 or 15 per cent in the amplitude of vibrations for a given applied force.

Turning now to some of the other points whcih have been raised in the discussion, other methods for measuring the vibrations of vehicle bodies have been cited. I believe I mentioned most of these in the body of the

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paper. There is one, however, which is new to me, the use of an elastic system having a very short period compared with the period of the body vibrations, and observing the motion of this system through a microscope. It seems hardly possible, however, that accurate reliable data can be obtained by this method. On the other hand, the use of the seismograph gives a full-size accurate visualization of the body vibrations, and an analysis of the curves gives the acceleration at any desired point. The seismograph can be used on any roads under all conditions, and to my mind is far more practicable than the optical methods. In fact, that was the whole reason for developing it.

The question of springbase versus wheelbase was raised. I have tried to indicate in the paper, using the simplest physical conceptions, why the distance on the frame between spring anchorages does not affect the riding qualities; only the actual wheelbase itself does this. As I have already indicated, this conclusion can be reached most simply by considering the matter from the standpoint of the quality of action and reaction. Perhaps the best experimental proof is the case cited by Mr. Crane, of the old runabout which employed a continuous spring running from front to rear, in which the effective distance between the spring anchorages on the frame was about 18 in.

A number of other questions were raised, such as the effect of unsprung weight, fore-and-aft flexibility and the balance of the car. These matters are rather outside the intended scope of my paper. The primary object of it was to point out the methods available for measuring vehicle vibrations and to incorporate a sufficient amount of the theory involved to enable a proper interpretation of the measurements to be made.

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THE VELOCITY OF FLAME PROPAGATION IN ENGINE CYLINDERS

By Donald MacKenzie[1] and R K Honaman[2]

Flame propagation has received much attention, but few results directly applicable to operating conditions have been obtained. The paper describes a method devised for measuring the rate of flame propagation in gaseous mixtures and some experiments made to coordinate the phenomena with the important factors entering into engine operation; it depends upon the fact that bodies at a high temperature ionize the space about them, the bodies being either inert substances or burning gases. Experiments were made which showed that across a spark-gap in an atmosphere of compressed gas, as in an engine cylinder, a potential difference can be maintained which is just below the breakdown potential in the compressed gas before ignition but which is sufficient to arc the gap after ignition has taken place and the flame has supplied ionization. These experiments and the recording of the results photographically are described. The spark chronograph, an instrument designed to replace the oscillograph used in these experiments, is also described and its advantages stated. The results so far obtained prove the fundamental idea that a voltage sufficient to arc a gap ionized by the ignition flame is not large enough to break down the compressed gas. A study of turbulence and knocking, using this method, concludes the paper.

Among the important phenomena occurring in the gas engine which are of interest from the point of view of physicists and engineers alike, probably none has received so much attention as flame propagation with the accumulation of so few results directly applicable to operating conditions. Engine performance is very greatly influenced by the manner in which the pressure in the cylinder rises after ignition has taken place and burning progresses. In fact, the efficient use

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of the chemical energy of the gas depends among other things upon timing the ignition with relation to the position of the piston so that a maximum amount of the chemical energy is transformed into mechanical energy at the crankshaft. Moreover, the rate of rise of pressure is determined by the rate at which the flame spreads through the gaseous mixture.

This paper describes a method which has been devised for measuring the rate of flame propagation in gaseous mixtures and some experiments which have been made to coordinate the phenomena with the important factors entering into engine operation. The method used depends upon the fact that bodies at a high temperature ionize the space about them. These hot bodies may be inert substances or burning gases. For example, the flame in an engine cylinder constitutes such an ionizing agent. A spark-gap when bathed by the flame becomes a conducting medium and permits the discharge of a condenser, the terminals of which are connected to the electrodes of the spark-plug.

To make use of this phenomenon in the engine cylinder, experiments were made which showed that across a spark-gap in an atmosphere of compressed gas, such as that in an engine cylinder, a potential difference may be maintained which is just below the breakdown potential in the compressed gas before ignition, but which is sufficient to arc the gap after ignition has taken place and the flame has supplied ionization.

A cylinder-head in which the velocity is to be measured is arranged to take three spark-plugs Nos. 1, 2 and 3, all placed above the dead-center position of the piston. Plugs Nos. 2 and 3 are connected to a source of comparatively high electrical potential just before current for ignition is supplied to plug No. 1. At the high pressure existing in the cylinder during the latter part of the compression stroke, these gaps will not allow discharge. However, when the charge is ignited at plug No. 1, flame spreads out in all directions and ionizes the gas in gaps Nos. 2 and 3, permitting current from the source to discharge through them. By suitably connecting a recording device to register the instants when the igniting current is supplied to plug No. 1 and gaps Nos. 2 and 3 are ionized, and by determining therefrom the time required for flame to travel between plugs Nos. 1 and 2, and Nos. 1 and 3, the average velocity of the flame between these points is obtained.

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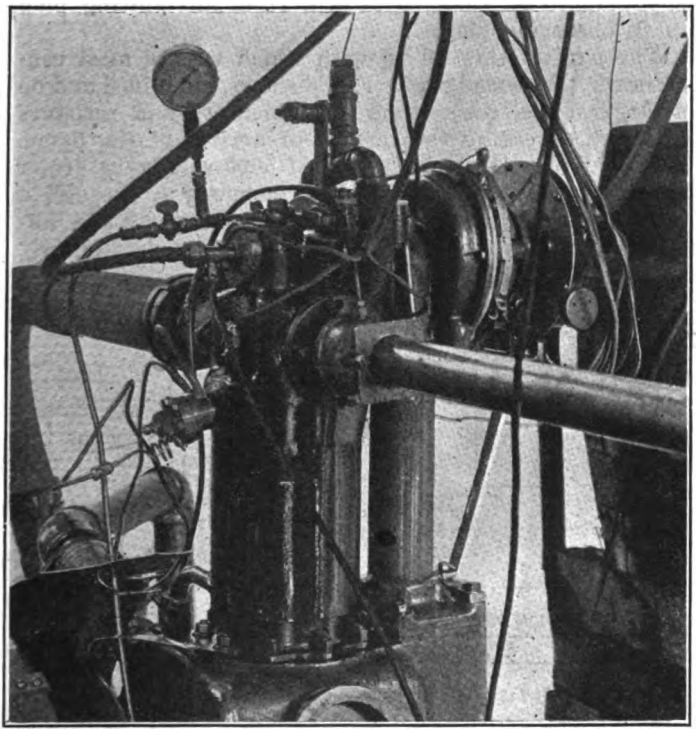

FIG. 1—ONE-CYLINDER LIBERTY ENGINE

HOW THE EXPERIMENTS WERE CONDUCTED

The experimental work was done on a one-cylinder Liberty engine, shown in Fig. 1. Fig. 2 is a complete wiring diagram of the electrical apparatus connected with the engine. In general it may be divided into three parts. The first is a standard Delco ignition system as supplied for use on Liberty engines. This includes two separate coils, a generator and a battery. The second is an arrangement of condensers and resistors that are used for determining the instant when the flame arrives at the observing spark-plugs. The third is a selector switchboard through which either of the two ignition coils and either of the two condensers can be connected to any one of the three spark-plugs, thus making the system entirely flexible and permitting

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any plug to be changed at will from an igniting plug to an observing plug.

The part of this set-up with which we are most concerned is the second part. Fig. 3 shows, simplified and on a larger scale, the system of condensers and resistors used for observing the instant of arrival of the flame. In this figure is shown a 100 to 5000-volt transformer which supplies the charge to condenser c_2 through a kenotron rectifying valve, high resistance r_2, and another rectifying valve v. The condenser c_1 is similarly

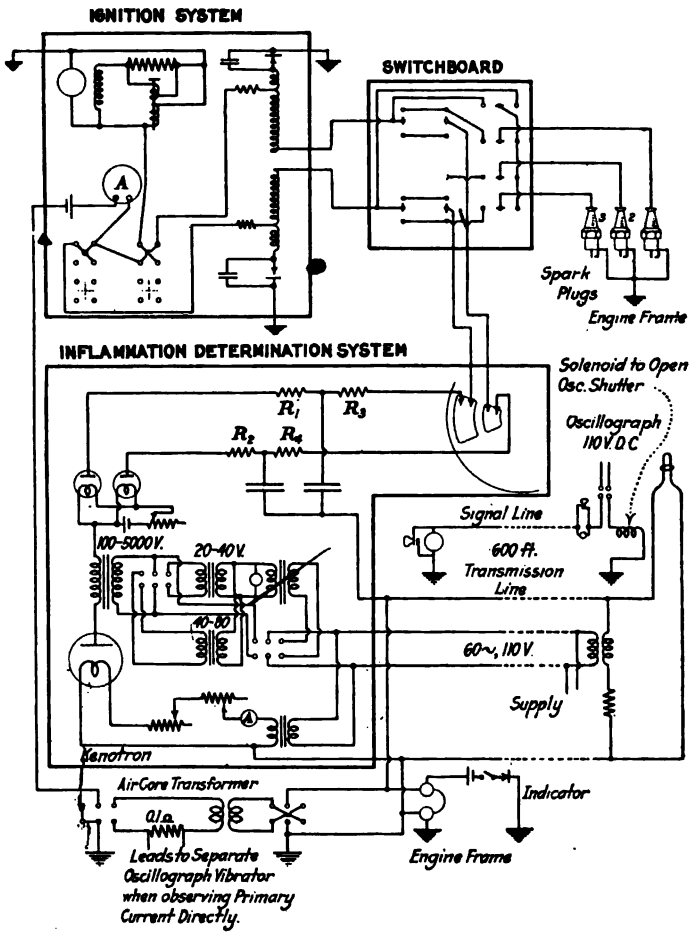

FIG. 2—WIRING DIAGRAM OF ELECTRICAL APPARATUS CONNECTED WITH ENGINE SHOWN IN FIG. 1

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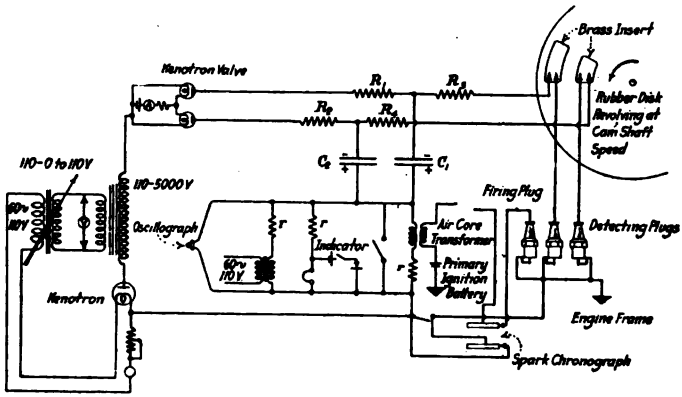

FIG. 3—CONDENSERS AND RESISTORS FOR OBSERVING INSTANT OF FLAME ARRIVAL

charged through resistance r_1 and the valve associated with that circuit. The oscillograph vibrator, connected to the engine laboratory through a 600-ft. transmission line, is permanently in series with these two condensers. Furthermore, the condensers are connected through resistances r_3 and r_4 and through the contact-timing disk to spark-plugs Nos. 2 and 3. It will be noted that the oscillograph vibrator is also in series with this circuit. A battery ignition system supplies current to spark-plug No. 1. The instant of ignition is also recorded by the oscillograph vibrator by a small air-core transformer. The primary of this transformer is connected in series with the primary circuit of the ignition system and its secondary is in series with the oscillograph vibrator. When igniting current is supplied to spark-plug No. 1 by the opening of the primary contact-maker, the sudden decrease in current in the primary of the air-core transformer induces an electromotive force in its secondary and causes a deflection of the vibrator. After ignition, the flame reaches plugs Nos. 2 and 3 successively, discharging at the corresponding instants condensers c_1 and c_2 through resistances r_3 and r_4, and through the oscillograph vibrator, producing two successive deflections of the latter. The contact-disk, driven through gearing from the camshaft, serves the purpose of connecting the condensers to their proper spark-plugs only after the cylinder pressure has become sufficiently high to insure against breakdown be-

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fore ionization by the flame. The phase of this disk is adjustable at will.

Resistances r_1 and r_2 are made about forty to fifty times larger than r_3 and r_4 so that very little current will be supplied from the alternating-current source to the spark-plug circuit; also, that the charging of condensers c_1 and c_2 shall be accomplished by a small current over a comparatively long time, and that the discharge through r_3 and r_4 shall be effected by a comparatively large current over a very short period, thus giving a sharp discharge signal on the oscillograph and charging signals that are broad and flat. The values are about 600,000 ohms for r_1 and r_2, and 15,000 ohms for r_3 and r_4. The condensers have a capacity of 0.0034 mf. It was found convenient to charge the condensers to a potential of about 3000 volts. Under these conditions, the initial discharge-current is about 0.1 amp., giving a 2-cm. deflection of the oscillograph vibrator. Moreover, the maximum charging current is not more than 0.005 amp., which gives a vibrator deflection of less than 1 mm.

The rectifying valves serve to isolate the condensers from each other during the discharge period. It was found that if r_1 and r_2 be directly connected, condenser No. 2 sometimes discharges through r_1, r_3 and r_3 into spark-plug No. 2, so that its potential is very greatly reduced before ionization occurs in spark-plug No. 3 and discharge can take place. These rectifying valves allow charging to take place freely but prevent any interaction of the two discharging circuits.

The discharge signals in the oscillograph were superimposed upon a 60-cycle wave from an alternating-current source, so that the oscillograph shutter might be kept open for several revolutions of the drum without having the observations overlap. The effect of this will be shown in a later figure.

Recording the Results Photographically

This same set-up has also been arranged to show on the films the instant when maximum pressure is reached in the cylinder. The apparatus for accomplishing this is also shown in Fig 3, which is a skeleton diagram equivalent to Fig. 2. The contact-maker, not shown in Fig. 3, is a diaphragm and pin. One side of the diaphragm is exposed to the pressure of the engine gas and the other side to a controllable static pressure. The

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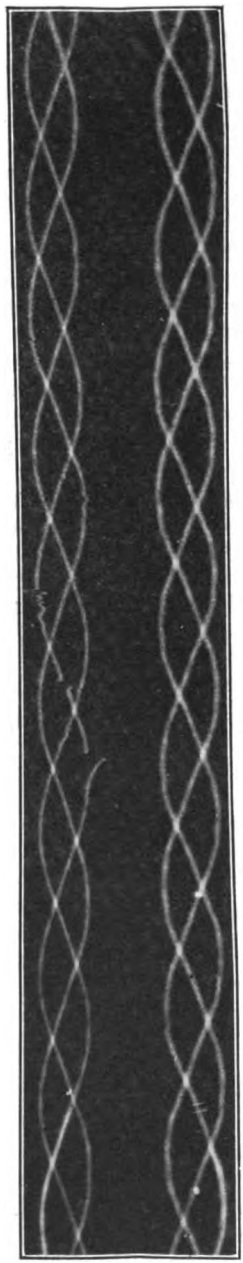

FIG. 4—TYPE OF RECORD OBTAINED

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static pressure is raised so that at no time during the engine cycle does the diaphragm make contact. It is then gradually lowered until contact is made during one short interval in each cycle, as shown by a click in the telephone receiver. This is obviously during the instant of maximum pressure. Current from a small battery, not shown in Fig. 3, then flows during this short interval, adding another excursion of the oscillograph vibrator. This permits a determination of the instant of maximum pressure in relation to the piston position. A complete description of the indicator is given on page 321 of this volume.

Fig. 4 shows the type of record that was obtained. The first excursion of the vibrator occurred when the ignition current was supplied through the air-core transformer to spark-plug No. 1, and as spark-gaps Nos. 2 and 3 were ionized and condensers c_1 and c_2 discharged through them, the second and the third excursions were made. The frequency of the alternating-current wave is known and consequently the time between ignition and each of the excursions can be determined. Fig. 4 does not show the type of record obtained for the maximum-pressure determination, but the apparatus can be designed so that an additional record is obtained at the instant of maximum pressure.

The three waves were traced during three successive revolutions of the drum and the speed was adjusted so that the observed displacement was obtained. The first excursion shows the instant that current is supplied to the igniting spark-plug; the second and third excursions indicate the succeeding instants when ionization takes place in the observing plugs. It might be noted that the ignition signal is made up of several oscillations; these are probably caused by the fact that the rate of change of the primary current of the ignition system is fluctuating, giving variations in the voltage in the secondary of the air-core transformer.

To release the oscillograph for other investigations, an instrument has been designed to replace it for this work. The new recording device may be known as a spark chronograph. This consists of a cylinder of electrical insulating material containing brass-ring inserts, about which are rotated metallic sparking points radially placed. If a sheet of carbon paper is placed on the cylinder a small spark-gap is formed between the sparking points and the metal rings, and the paper is punc-

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tured. Fig. 3 shows diagrammatically the location of such an instrument.

The Spark Chronograph

Fig. 5 shows the spark chronograph that will replace the oscillograph. In this way there is obtained an estimate of the variation in flame propagation from cycle to cycle. The spark is easily visible and should occur at the same position on the drum, when the sparking points are rotated synchronously with the engine. If the spark moves about from point to point, it is evident that the instant of ionization for that particular spark-plug is changing from cycle to cycle. In obtaining a record, the spark chronograph must be left running as long as desired and the discharge current will then puncture a new hole for each engine cycle. The center of this group of holes is then the average position for the instant of ionization in the corresponding plug, taken

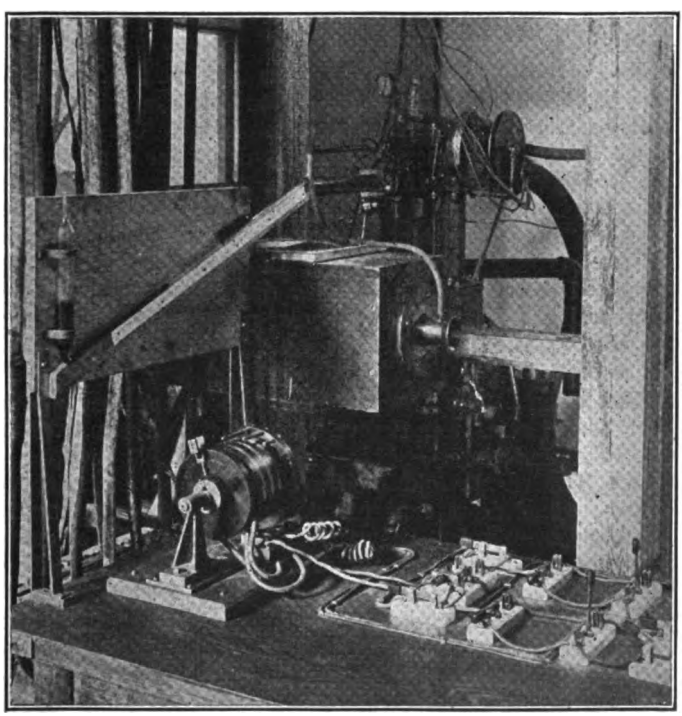

Fig. 5—Spark Chronograph

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throughout the operating period of the chronograph. The ignition current is also permitted to make a record on the sheet, under another spark-plug.

The spark chronograph can also give a visual indication of the velocity of flame propagation. A disk with sight-vanes is rotatable about the axis of the chronograph drum and is graduated to show the position of the sight-line in degrees from a given reference point. The sight-line is first set on the spark made by the ignition system and is then turned to the spark caused by current discharging through one of the spark-plugs; the angular distance through which it is moved is then noted. Calling this angle θ and the distance between the spark-plugs in meters d, the velocity of flame propagation can be determined directly from the formula:

$$v = \frac{6nd}{\theta - \alpha} \text{ where}$$

n = the speed in r.p.m.; and
α = 18 deg., the fixed angular separation of the ignition and condenser gaps.

The results so far obtained show that the fundamental idea involved in this method is sound, namely, that a voltage sufficient to arc a gap ionized by the ignition flame is not large enough to break down the compressed gas. To test this in each case we have determined that the voltage used on the plugs would not interfere with engine operation. Measurements obtained from different records indicate that the velocity of flame propagation varies widely with different engine conditions and also that the velocity of propagation increases rapidly as the flame travels away from the point of ignition.

The value of the method already described lies in the fact that by its use the velocity of flame propagation can be studied in an engine while it is actually in operation. The results obtained are in marked contrast to those derived from experiments with explosive mixtures in closed vessels, but they furnish a safer basis for comparisons of fuels and for the designing of cylinder-heads.

In any particular engine, various fuels and different ignition systems may be studied and their relative merits indicated. Location of spark-plugs and shape of combustion space have an influence upon the time taken for complete inflammation and hence upon the interval

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between ignition and the attainment of maximum pressure. If several designs of cylinder-head are available, the method can be used to determine their relative merits.

Studying Turbulence and Knocking

Moreover, some conclusions can be drawn as to turbulence in the mixture, its magnitude and its effect upon horsepower output. By successively changing the functions of the three plugs, using No. 1 as the firing plug and Nos. 2 and 3 as observing plugs, then by changing the ignition to plug No. 2 and finally to plug No. 3, it is possible to compare the times occupied by the flame in traveling in two directions over each of three different paths. If the time interval from plug No. 1 to plug No. 3 is greater than that from plug No. 3 to plug No. 1, it might be concluded that a current of gas from plug No. 3 toward plug No. 1 gives a velocity to the flame in addition to its normal velocity of propagation.

Experiments have shown turbulence effects with velocities from 1 to 4 m. per sec. When the engine is fired at one plug alone and this is the one from which the flame-spread is accelerated by turbulence, measureably greater horsepower is developed, reaching in some cases an increase of 5 per cent over the output when the ignition takes place at an opposite plug.

During the development of the method of measurement mentioned, the output of the engine was absorbed by a fan brake. Under these circumstances close control of the speed is impossible, nor were there proper means for determining and holding a constant mixture ratio. The engine is at present coupled to a dynamometer and provision is made for obtaining more complete data.

The phenomena of knocking are not yet fully investigated, but it was observed that when violent knocking is heard the oscillograph records abnormally short time-intervals. If the spark is then retarded until knocking ceases, the time-interval recorded returns to its normal value. It is yet too early to predict how much information regarding knocking can be derived from studies of the velocity of flame propagation.

It is planned to compare different fuels in the engine and to study the variations in flame velocity with a change in the mixture ratio, compression pressure,

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throttling, spark advance and speed. Comparisons of various designs of cylinder-head are also hoped for.

The results of several hundred observations are given. The data were collected under these conditions:

Standard "X" gasoline
Mixture ratio, about 12 parts air to 1 of fuel
Speed, about 1400 r.p.m.
Full throttle and 30-deg. spark advance
Carbureter, Tice experimental

When results in opposite directions over the same path are averaged to eliminate the effect of turbulence, they appear as follows:

x=Distance, cm.	t=Time, sec.	Average Velocity=$\frac{x}{t}$ m. per sec.	ft. per sec.
2.8	0.00434	6.44	21.13
9.5	0.00872	10.87	35.66
11.8	0.00937	12.58	41.27

A later series of observations over the second of these distances, made with a Claudel carbureter, gave the result x=9.5 cm. and t=0.00858 sec. or practically the same as the value tabulated. These values of x and t satisfy within 1 per cent the empirical formula.

$$\frac{x}{t} = ax + b$$

From this we obtain

$$x = \frac{bt}{1-at} \text{ and } \frac{dx}{dt} = v = \frac{b}{(1-at)^2} \text{ or } b\ (\frac{a}{b}x + 1)^2$$

The flame velocity is seen to be low in comparison with the velocity of the air inflow, about 200 ft. per sec. The piston speed, 1600 ft. per min., is intermediate between the low and the high flame velocities observed, 1270 and 2480 ft. per min. respectively.

It is to be observed that this expression for the velocity of flame propagation involves two constants a and b, the ratio of which appears in the parenthesis as the coefficient of the distance from the firing plug. It may be conjectured that the constant b is a property of the fuel mixture used, while the appearance of x shows the effect of confinement of the explosion in the cylinder-head. This effect should depend upon both the fuel and the shape of the combustion space. It may develop that a is a coefficient whose value depends on the geometry of the explosion chamber. It is expected that fur-

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ther data will yield a criticism of this formula and perhaps a physical interpretation of it.

Writing v=velocity of flame propagation in centimeters per second, the constants have the value a=68.6, b=450; so that

$$v = \frac{450}{(1-68.6t)^2}, \text{ or } 450\ (0.153\ x + 1)^2$$

Inspection of the formula suggests at first that v increases without limit, but it must be remembered that t has a limit, namely, the instant when inflammation is complete and flame spread ceases.

THE DISCUSSION

DR. H. C. DICKINSON:—Professor Harold B. Dixon of England is one of a number of able scientists who have made a very extended study of the propagation of explosions in gas mixtures. I had the privilege of visiting his laboratory recently and spending a very profitable day discussing with him some of his past and present researches into this subject. The general problem which has led to most of the researches on gas explosions has been prevention of explosions in mines and in industries where accidental explosive mixtures may occur. The applicability of the results to gas-engine problems is rather accidental.

In 1893 Professor Dixon published a paper in the Philosophical Transactions of the Royal Society of London covering a research on explosions of various gas mixtures confined in long pipes of small diameter, in which he had repeated and verified the experiments of many previous observers and added much new information on the detonation velocities of explosion waves. It appears that in general an explosion wave starts out with a low velocity which increases gradually to a definite limit, after which it is constant no matter what the distance. This final constant velocity only was considered in the paper just mentioned, and in 1903 Professor Dixon published in the same journal a second very interesting paper, continuing this research and including also a study of the initial stages of explosions in glass tubes. Some of the results, to my mind, throw important light on the phenomena of fuel knock, as will be discussed later.

Professor Dixon's laboratory is typical of all the laboratories I visited in England, in that no time or money is wasted on elaborate instruments or equipment. This

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is in marked contrast to laboratory practice in this country and not to the credit of American methods. For the several important problems now in progress there is not a single piece of experimental equipment which could not be improvised in a few days at very little expense, and yet one will hardly find more accurate and careful work in progress anywhere. One experiment is intended to find the normal ignition temperature of mixtures of pentane, alcohol, ether, etc., with air. This measurement has commonly been made by flowing the mixture past a hot wire or by some such device. This is recognized as open to very grave question. The results may be hundreds of degrees in error, mainly due to catalytic action of the heated metal. Professor Dixon has devised a simple method which seems to avoid the error. The combustible gas and the air are heated independently in separate tubes and allowed to flow together when hot, and the temperature at which the gas takes fire is noted. There are, of course, some questions of accuracy involved here, but they are less serious than with other methods. Another problem is to determine the compression ratio at which such mixtures as the above will fire spontaneously under adiabatic compression. For this purpose the professor uses a tight-fitting piston in a long cylinder with a small pile-driver to produce the compression and a positive stop to limit the motion of the piston. He is studying the behavior of various substances and mixture ratios in this way. For the measurement of detonation velocities, which is being applied to a large number of gas mixtures not previously studied, there is a 100-meter pipe, 1 in. in diameter, coiled up in a wash-tub of water. A thin strip of silver foil is blown out by the explosion wave near the firing end of the tube and another near the far end of the tube; each breaks an electric circuit, causing a spark, and the interval between these is the time required to travel about 100 yd., this requiring somewhere between 0.1 and 0.01 sec. This is only a part of the important work in progress at Professor Dixon's laboratory.

As for the bearing of Professor Dixon's results and others of a similar nature on fuel knock in engine cylinders, I believe a careful analysis of these results offers a very interesting if not conclusive explanation of the mechanics of this effect. When an explosion wave is started it travels slowly, as we have shown by measurements, but it ultimately reaches a very high velocity, this

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velocity being sometimes 10,000 ft. per sec. The final velocity is practically independent of pressure, so that it would be about the same in a cylinder at 5 atmospheres as in a pipe at 1 atmosphere pressure. While the distance which the explosion wave travels before reaching its maximum speed in most of Professor Dixon's experiments is much too great to occur in an engine cylinder, this distance is very sensitive to changes of pressure and quality of mixture. A calculation from his results shows that at cylinder pressure, with gas mixtures likely to occur, it is quite possible for these detonations or maximum velocities to occur within the engine cylinders.

If such is the case, let us consider what may happen. In the first place, the mass of the charge never burns simultaneously, but in a progressive wave the speed of which is, however, enormously great. This wave always spreads out from the ignition point with a smooth wave-front something as a wave on the surface of the water, except in three dimensions. The instantaneous pressure at the front of the wave may be as much as 100 atmospheres when the initial pressure is 1 atmosphere, and the formula for the maximum pressure shows it to be proportioned to the initial pressure; thus, in a cylinder it might reach several thousand pounds per square inch. This pressure, however, lasts only for about 1/10,000 of a second, as shown by Professor Dixon's photographs, and it is not a true pressure in the usual sense, because it is due to the impact of a wave of gas molecules traveling at an enormously high speed but with very little weight or pressure behind it. When such a wave-front meets the wall of a cylinder it is like a shotgun charge of very fine shot striking almost simultaneously and would be expected to produce the sort of sound which we know to result.

Now if the position of the ignition point is such that the detonation wave-front reaches some part of the cylinder wall like a wave striking shore in an exact on-shore wind the effect will be greatest. If the wave strikes diagonally due to change in spark-plug position or cylinder shape, the effect may be less. Finally, the impact of such a wave would produce an amount of sound all out of proportion to the mechanical effects, since the inertia of the gas, due to its very small weight, is too small to impart any great mechanical action to the engine parts.

For this reason the actual instantaneous pressure can probably not be measured with any approach to accuracy.

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If applied to a piston even of the lightest weight, the inertia is many times too great to permit any accurate measurement. If applied to a light diaphragm, still the inertia is too great; also such a diaphragm requires a support which would further interfere with measurements. Some other methods might be better for the purpose. One of these was applied by Professor Dixon. If a high-speed wave of this sort strikes a glass wall and the glass wall is broken, it is almost certain that the instantaneous pressure was at least as great as would be the steady pressure necessary to break the glass. We know of only one other method which might be superior to this for the purpose.

PROF. C. A. NORMAN:—This paper is a valuable first step in an investigation of flame propagation and combustion phenonema in a high-speed internal-combustion engine under actual working conditions.

The maximum speed of flame propagation noted was 41.27 ft. per sec., applicable to comparatively long distances of travel; the minimum speed was 21.13 ft. per sec., applicable to short distances. The engine ran at 1400 r.p.m. A half stroke consumed 0.021 sec. The maximum distance traveled by the flame in this time would be about 11 in. In other words, the combustion would have time to spread throughout the whole charge during the time occupied by the working stroke, even in engines somewhat larger than the Liberty. Assume, on the other hand, that, during the comparatively slow travel of the piston near dead-center, we could consider the combustion space as retaining practically constant volume for as much as one-eighth of a revolution, in this case about 0.005 sec. With application of the minimum speed of propagation in this more limited space, the distance of travel in the interval considered would be from 1.3 to 1.5 in. It is thus evident that the flame would not spread through the whole combustion space in the time mentioned and that combustion would not take place at constant volume. Even with the comparatively rich mixture and the high-grade gasoline used, combustion would in all likelihood continue during almost the whole stroke, with a resultant unfavorable effect on fuel consumption.

Investigations of the character here carried out, but in connection with indicator diagrams showing the pressure conditions in the engine, would be of the very greatest interest for further understanding of the combustion process and its conversion into power.

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In conjunction with B. Stockfleth of the International Harvester Co., I have found best fuel economy for a 4 x 6-in. engine between 400 and 600 r.p.m., even though the mean effective pressure and the power were well sustained at much higher speeds; this, using ordinary gasoline. A fractional distillation test of the fuel used would be a valuable addition to the data furnished in the paper.

R. K. HONAMAN:—It is quite true that some very enlightening laboratory work in connection with this subject was done a great many years ago, and this differs from most engineering matters in that the time between the discovery of some of the facts which Professor Dixon made in the laboratory from the physicist's point of view, and the application of them to practical fields of work by the engineers, has been very long. There have been two reasons for this. In the first place it has been extremely difficult to get an adequate conception of what the character of propagation in an operating cylinder is. The facts were very obscure. Moreover, it has been possible in the past to build engines that worked satisfactorily and sold in competition without going into too great detail about such points as flame propagation which may have been considered abstruse. Now, however, conditions are changing. Fuel is becoming scarce and more expensive; power requirements are going up. As engines become more and more efficient, competition becomes keener, and factors which have been considered negligible and of academic significance only are rapidly becoming known to be important.

The second point is that it has not been entirely clear just how the results of laboratory investigations in this connection fit in with the practical application, if they fit in at all. This too has partly been due to the fact that detailed knowledge about processes occurring in the engine cylinder has been almost impossible to obtain; also no one has denied that differences should be expected between the behavior of a certain gas in a laboratory cylinder and the behavior of the same gas in an operating engine, not to mention the unavoidable difference in chemical composition and ignorance of the exact mixture that the engine uses. However, with the application of scientific methods to the physics of gas-engine operation, some of these points have been brought to light. Probably the most important development along this line has been that of the gas engine indicator.

The adaptation of the Piezo-electric crystal and Pro-

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fessor Thomson's method of measuring the velocity of positive rays for indicating cyclic cylinder pressures was considered by me and others several years ago. I do not know what confidence Professor Thomson had in the results of his depth charge pressure measurements by this method, but there is certainly a great difference between the two problems. In the first place, Professor Thomson had in each case only one discharge of very great intensity, whereas in the gas engine problem the large number of succeeding cycles of pressure are of more moderate intensity. One of the greatest objections to which all indicators of high-speed work are open is the error introduced by the length of gas column communicating between the surface which response to the pressure and the region for which pressure is to be measured. Unless this distance is extremely small it is bound to have an appreciable influence due to the inertia of the gas. It would seem also in the practical case that one could not hope to place the crystal very close to the heart of the cylinder lest the indicator should be destroyed before the engine was well up to speed. Moreover, the difficulty of fixing the crystal rigidly so that its calibration does not change from cycle to cycle is not to be ignored.

To make this applicable for engineering work, the recording apparatus should be at least as simple as an ordinary electromagnetic oscillograph, and preferably simpler, but the Piezo crystal does not deliver sufficient energy to operate an instrument of this type by a very large factor, and the question of amplification opens up all possibilities of wave-form distortion, etc. It would seem that a more feasible indicator might be made by seeking out some material whose electrical resistance varies appreciably with changes in pressure over the range found in the gas engine, much as the carbon granules of a microphone vary with the slight pressures of a sound-wave. If some such material could be found in sufficiently rugged and sufficiently refractory form, it could be placed anywhere in the cylinder walls, and probably with some difficulty in a moving piston in series with a battery and an oscillograph, and would give a reliable record with a maximum of convenience and speed.

The observance of a number of these phenomena depends upon the adaptation of electrical methods, as in the case of the study of flame propagation, and it will be of profound importance if the difficulties with either the

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Piezo or the pressure resistance method can be overcome. In any event, the Society is to be congratulated upon the fact that its members are bending every effort to get to the root of some fundamental physical facts involved in gas-engine operation and design, reacting inevitably on the industry as a whole, perhaps leading ultimately to the ability to predict with high precision the performance of a gas engine when the most fundamental physical constants are known.

HIGH-SPEED INDICATORS

By Thomas Midgley, Jr[1]

The indicator was an important factor in the early development of the internal-combustion engine when engine speeds were low, but on high-speed engines such indicators were unable to reliably reproduce records because of the inertia effects of the moving part of the pressure element. The first need is for a purely qualitative indicator of the so-called optical type, to secure a complete and instantaneous mental picture of the pressure events of the cycle; the second need is for a purely quantitative instrument for obtaining an exact record of pressures. The common requirements for both are that the indicator timing shall correctly follow the positions of the crank and that the pressure recorded shall agree with the pressures developed within the combustion space. Following a discussion of these requirements, the author then describes the demonstration made of two high-speed indicators, inclusive of various illustrations that show the apparatus, and comments upon its performance. In conclusion, a description is given of a high-speed diaphragm indicator of the balanced-pressure type, developed at the Bureau of Standards.

An indicator is an instrument for getting a graphical representation of the pressures within an engine cylinder, which are plotted against some other function of the engine such as the piston position or the crank angle. The original indicator was invented by James Watt and used by him in his great engineering work on the steam engine. In the early development of the internal-combustion engine the indicator played an important part as long

[1]Mechanical engineer, research division, Dayton Metal Products Co., Dayton, Ohio.

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as the speeds encountered were low, but with the rapid advance of the art to high-speed engines the instruments were unable to reproduce records at these higher speeds reliably because of the inertia effects of the moving parts of the pressure element.

Improvements upon indicators became necessary, and while it is interesting to note these developments they have without exception fallen short of the mark for exact-pressure studies. But there have been a few research laboratories where the indicator has been employed almost constantly in showing the variations of pressures; as in the development of valve-timings to serve a given speed range; the development of combustion-chamber form; the location of spark-plug electrodes; fuel studies, etc. In these applications it is unnecessary to know the values of the pressures but merely their general relationships; and the indicator so used becomes a purely qualitative instrument.

That there is a need for an instrument of great precision can scarcely be questioned, and that such an instrument will fill a field of broad usefulness can readily be proved by the results already obtained. But whatever our need for an ultra indicator of pressure values and its broad usefulness, the fact remains that for general use, where speed of observation is essential and where a picture of a single pressure cycle or an indication of the variations among successive cycles without necessarily a record of it is required, the highly developed and simple qualitative optical instrument will have wide application.

It is hoped that the foregoing has served in some measure to make clear the need for two classes of indicating instruments; first, a purely qualitative one of the so-called optical type with which a complete and instantaneous mental picture of the pressure events of the cycle is secured; and, second, a purely quantitative type of instrument, with which an exact record of pressures can be obtained. The common requirements in both types are (*a*) that the timing of the indicator shall correctly follow the positions of the crank and (*b*) that the pressure recorded shall agree with the pressures developed within the combustion space.

In any discussion of the foregoing requirements, the first is most easily satisfied. The nature of the motion-transmitting mechanism will depend, in the optical type, upon the kind of diagram sought; i.e., whether the pressure is plotted against the piston positions, called the

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pressure-volume diagram, or against the crank angle, called the pressure-time diagram. To secure the former, which is that from which the mean effective pressure is determined, it is necessary to oscillate the indicator mechanism in synchronism with the piston of the engine. This involves a reproduction in the indicator mechanism of the engine crank-rod ratio, and also of the crank offset, if any. This drive involves joints and bearings which must be free from back-lash. All these parts are avoided in the drive for making pressure-time diagrams, a simple, continuous rotary motion being all that is necessary. In the optical type for fuel studies, the pressure-time form of diagram is superior, since the pressure events are expressed directly in terms of the crank angle; and the interesting phenomena at the ends of the strokes are not hidden through crowding, as in the pressure-volume diagram. This will be observed from some of the studies shown. In the polar pressure-time diagram the atmospheric line is a circle and the pressure ordinates are radii of the circle.

The second requirement, perfect agreement between recorded and actual pressures, is satisfied only with a negligible length of passage between the cylinder and the pressure-deflected portion of the indicator; and in indicator work at high engine speeds the only passage having a negligible length is one having none at all. This limits us to the use of a spring-controlled piston in the pressure element, since the popular diaphragm of the conventional optical indicator cannot be subjected to the temperatures of the combustion-chamber gases, inasmuch as it must serve as its own spring. In the case of the ultra indicator hereinafter described, the diaphragm is not a spring, and hence can be and is exposed to the hot gases. The elimination of vibration troubles in the pressure element is most difficult of solution and is only satisfied through very careful design.

We will now demonstrate two instruments. One of these represents a high degree of perfection of the relative type for optical study combined with a degree of accuracy which is well within the accepted limits of engineering. The other indicator, developed at the National Bureau of Standards, is, we believe, the highest development of the second class, possessing accuracy to a most remarkable degree. It is unfortunate that the only principle so far advanced that permits of practical embodiment in an instrument of extreme accuracy is one which

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cannot be combined with the desirability of optical observation. This latter indicator is to a large extent the child of adversity, as its development was necessary to make any such studies whatsoever in the altitude chamber. For this reason it deserves special credit as a most remarkable piece of research work.

In the conventional type of steam-engine indicator, typical of those used in the early days and still used on large installations of stationary engines where the speeds are slow, a piston is exposed to the cylinder pressures

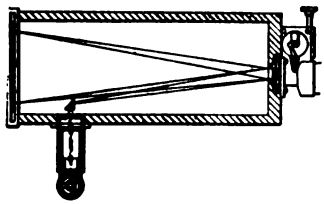
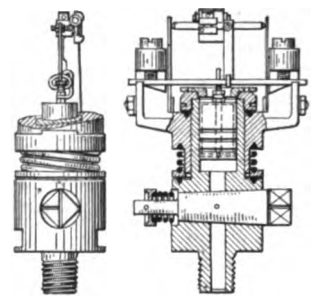


FIG. 1—MANOGRAPH



HOPKINSON INSTRUMENT

through a connecting pipe which also serves to keep the gases cool, and its deflection is resisted by a calibrated spring. This motion is transmitted through a series of levers and is recorded by a pencil on a paper fastened to the drum which in turn is oscillated by a string connection to some portion of the engine.

The instrument known as the manograph (Fig. 1) represents the next type of advance. A diaphragm is made use of in the pressure element; but the big contribution made to the art by this instrument is the beam of light which is used to replace the moving arms of the preceding type. I have already mentioned the disadvantages of the diaphragm. It cannot be subjected to heat and retain its spring qualities. Another serious disadvantage is its irregular calibration, which gives trouble if the instrument is used in any other than a purely qualitative way.

As an improvement upon the manograph, Prof. Hopkinson devised the instrument shown at the right of Fig. 1. This is a reversion to the piston-type instrument but, because of the type of spring used, the calibration is still far from perfect. This development failed to

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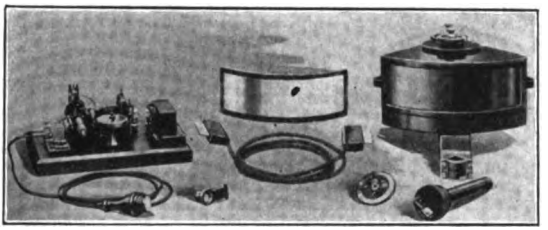

FIG. 2—PARTS OF BUREAU OF STANDARDS OPTICAL INSTRUMENT

make use of one of the greatest assets of the piston-type pressure elements, that is the ability to get right down on the wall of the cylinder-head and thus eliminate all connecting pipes and chambers.

The parts of one of the instruments developed by the Bureau of Standards are shown in Fig. 2. This instrument is shown in more detail in Fig. 3 which is a cut of the pressure element of the instrument shown in Fig. 2. The element is of the piston-type and is compactly arranged in a unit, one end of which screws directly into the combustion chamber. Pressure in the cylinder operates against the piston to compress the resisting spring. This movement is transmitted through a very light shaft to an arm which operates to change the vertical angle of

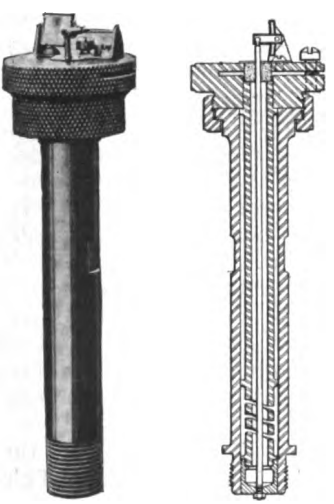

FIG. 3—PRESSURE ELEMENT OF BUREAU OF STANDARDS OPTICAL INSTRUMENT

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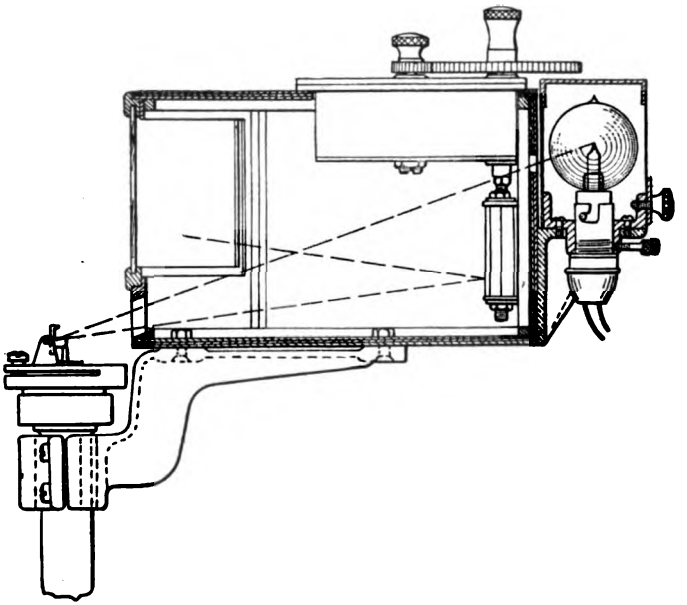

FIG. 4—CROSS-SECTION OF BOX OF BUREAU OF STANDARDS OPTICAL INSTRUMENT

a mirror supported on a horizontal axis in proportion to the pressure on the piston. A cross-section of the box, showing the arrangement of lamp, pressure element, revolving mirror, ground-glass front, etc., is shown in Fig. 4.

Fig. 5 shows the optical system. When the system is in operation, light issues from a small aperture in a metal casing surrounding the light bulb, which is supported on the back of the motor box. This beam of light passes through the motor box to the concave mirror on top of the pressure element. It is reflected and focussed by the pressure-element mirror, and again traverses the length of the motor box to the eight-sided mirror in the rear, which can be either oscillated or revolved, according to whether pressure-volume or pressure-time cards are desired. The convergent rays of light from the pressure-element mirror, after being reflected by the eight-sided mirror, are projected forward upon the curved glass forming the front of the motor box. This point of light moves up and down with a corresponding change in the angle of the pressure mirror. At the same time it moves

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horizontally with the oscillation or rotation of the octagonal mirror, thus tracing out on the curved glass either pressure-volume or pressure-time cards. Fig. 5 is also representative of the arrangement which gives pressure-volume cards. Included in the crankshaft attachment is a member driven by a crank attached to the distributor head and having a reciprocating motion in a vertical direction. A fine wire is attached to this member and carried over a light pulley to an arm which transforms the reciprocating motion into an oscillation of the eight-sided mirror about its vertical axis.

The synchronizer, shown in Fig. 6, is used in taking pressure-time cards. Its function is to rotate the eight-sided mirror located within the motor box, so that its speed can always bear the same definite ratio to the speed of the engine. The system comprises a mechanism for attachment to the engine or dynamometer shaft, and a synchronizer and rotating mirror in the motor box. The synchronism is accomplished electrically by energizing the coils of the synchronizer through a distributor operated by the shaft of the crankshaft attachment. To take photographic records of cards, it is only necessary to replace the ground glass with a clear glass, hold a piece of bromide paper against the glass and press a button. The bromide paper is developed and a single card is found. This result is accomplished very simply by elec-

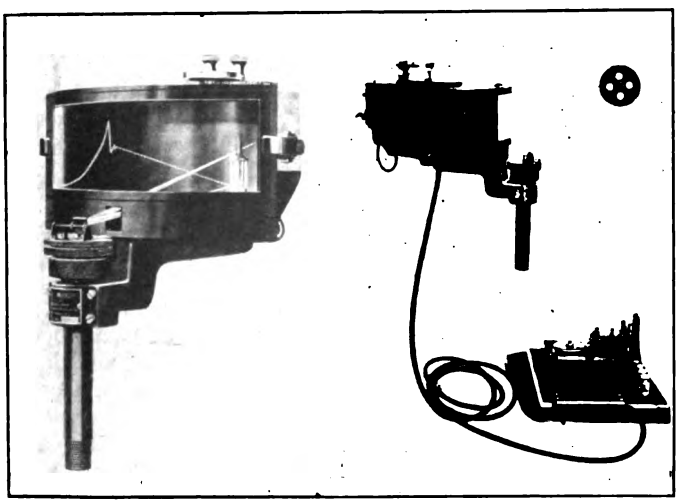

FIG. 5—OPTICAL SYSTEM OF BUREAU OF STANDARDS INSTRUMENT

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trical means, merely a timing device which subjects the lamp to two or three times its rated voltage for two revolutions of the engine. The time of two revolutions is too short to burn out the lamp until it has given a thousand or more cards. Fig. 7 shows the indicator installed in a dynamometer room and the operator taking a card.

Fig. 8 is the representation of a study which this in-

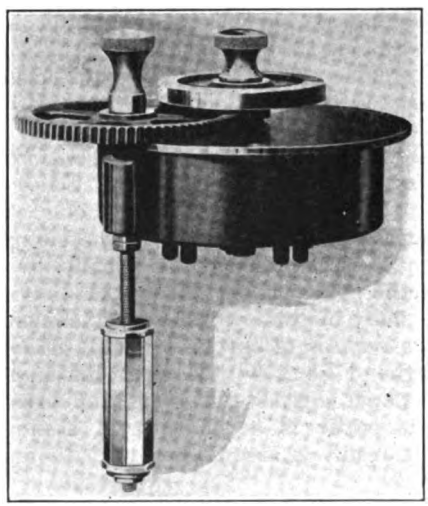

FIG. 6—SYNCHRONIZER USED IN TAKING PRESSURE-TIME CARDS

dicator has made possible. This is a fuel study of gasoline upon a Delco-Light engine which was purposely put out of adjustment to study the knocking tendencies of various fuels. Notice upon the pressure-time card, following from left to right, the rise on compression, the point at which ignition takes place; then the smooth rise along the combustion line, passing the dead-center at about the maximum pressure; then the almost immediate drop of pressure, due to the downward movement of the piston and the expansion of the gas; and finally, the opening of the exhaust valve. Again, from left to right, the results of the exhaust stroke are traced by a second beam of light. Notice now the drop of pressure as the intake stroke commences. And, passing to the right of the card. the same cycle would be repeated. This card is typical of a gasoline from a paraffin-base crude. Notice that the pressure-volume card shows but few of the character-

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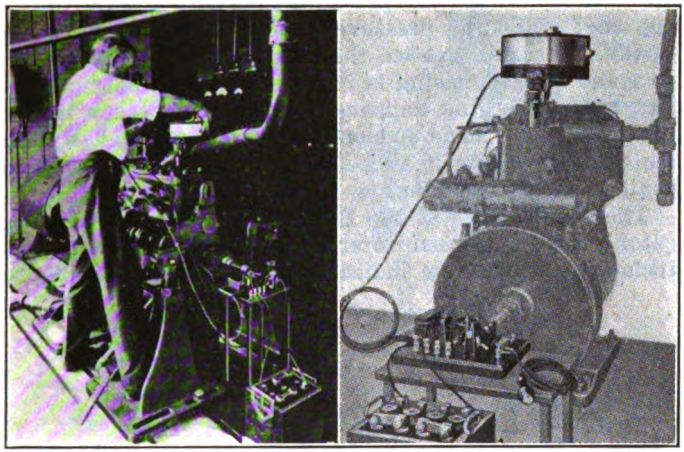

FIG. 7—INDICATOR INSTALLED IN DYNAMOMETER ROOM

istics of the fuel. The distillation curve of the gasoline is shown.

In Fig. 9 is shown a study of a sample of kerosene made on the same engine and refined from the same crude oil as was the gasoline. This engine was purposely put out of adjustment to study knocking of the fuel. The spark is intentionally early; the carbureter was purposely formed within the cylinder-head. Notice now the

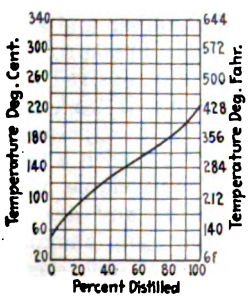

FIG. 8—GASOLINE STUDY

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differences between this pressure-time card and the previous one; while the pressure-volume card remains practically the same. Notice the rise on compression as before and that the rising is in a perfectly normal manner. But here something happens that does not occur in the previous case. Some sudden rise of pressure takes place and this exerts itself as a sharp "pink," which is called preignition or knocking.

The development at the Bureau of Standards of indicators for high-speed internal-combustion engines has included a diaphragm indicator of the balanced-pressure

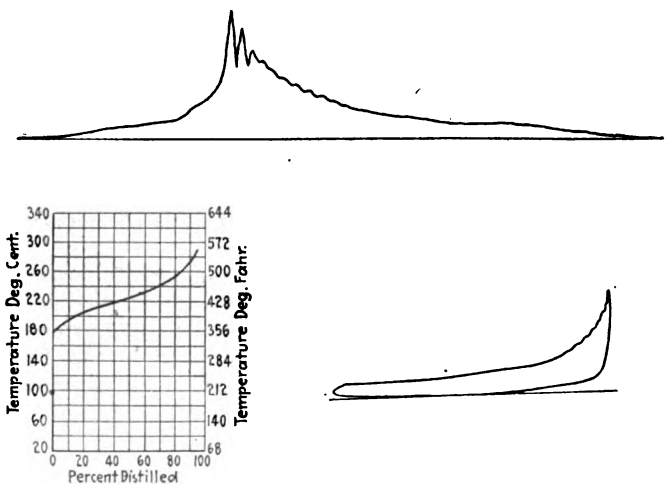

FIG. 9—KEROSENE STUDY

type that has proved thoroughly successful. It (See Fig. 10) consists of a steel diaphragm about ¾ in. in diameter and 0.002 in. thick, clamped in a small chamber and subjected on one side to the varying cylinder pressure and on the other to a constant pressure of any desired and measurable value, supplied by a compressed-air tank system or a vacuum system. An electric contact point is located above the diaphragm and is in circuit with a telephone or spark-coil indicator when this controllable pressure just balances the engine pressure at any desired phase in the engine cycle. The diaphragm chamber screws directly into a hole in the engine cylinder-head, an extra spark-plug hole, eliminating uncertainties due to long connecting pipes and leaving the clearance volume

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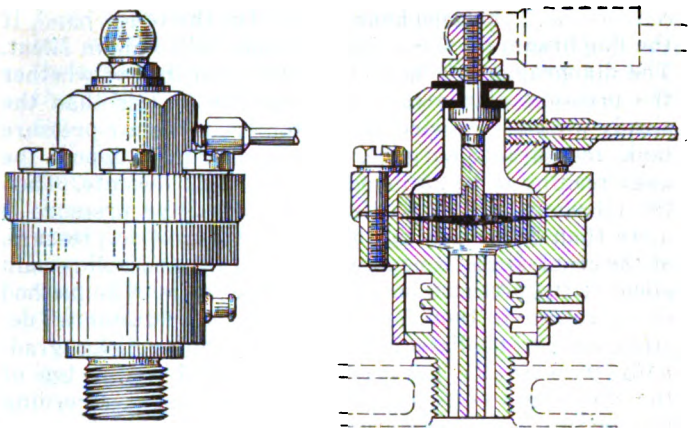

FIG. 10—BUREAU OF STANDARDS DIAPHRAGM INDICATOR

unchanged. The only moving part is the 0.002-in. thick diaphragm, which moves but a few thousandths of an inch, will respond to instantaneous pressure without error, and is practically unaffected by vibration. The record obtained is an average from the same phase of many consecutive cycles, although a point or click is observed for each cycle.

The commutating segment in series with the telephone (See Fig. 11) makes contact once per engine revolution. If at the time of this contact the diaphragm be in the upper position against the electrode, the electric circuit is

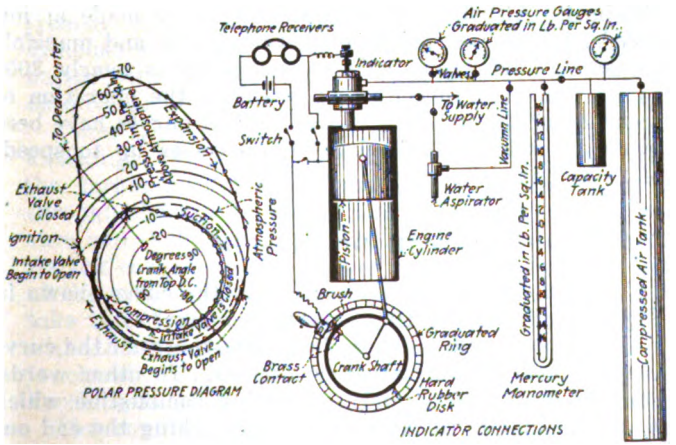

FIG. 11—COMMUTATING SEGMENT IN SERIES WITH TELEPHONE

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complete and the telephone clicks. On the other hand, if the diaphragm be down, the telephone will remain silent. The diaphragm will be up or down according to whether the pressure at the instant is greater or less than the steady pressure exerted on the top from the air-pressure tank, measurable by gage. As an example, suppose the gage reading to be 20 lb. per sq. in., 35 lb. absolute. Then the telephone will click whenever the engine pressure is more than 20 lb. per sq. in. above atmospheric pressure, at the crank angle of commutator contact, and will remain silent if the pressure be less than that value. The method of operating is therefore to set the commutator as desired and, while listening to the telephone clicks, gradually increase the gage pressure applied to the top of the diaphragm until the telephone clicks cease, recording this critical gage pressure.

The exact determination of the above point is possible only with exact repetition of pressure values every cycle in the engine. With the usual variations from cycle to cycle, what the observer hears as the critical value approaches is an intermittent clicking, say two, three or a half-dozen clicks, then perhaps half a second's silence, then a few more clicks, then another pause, etc. Some judgment must, therefore, be exercised in choosing the condition to select as representative of average pressure at the phase under measurement.

A specimen indicator card from pressure measurements every 10 deg. in the cycle of a Waukesha truck engine is reproduced in Fig. 11 to show what results can be obtained. Although these first runs were made at low speeds, later observations on both cylinder and manifold pressures have been made at speeds up to nearly 3000 r.p.m., and show no effect of speed on the operation or accuracy of the indicator. More recent curves have been made on cylinder and manifold pressures up to speeds of 2400 r.p.m.

THE DISCUSSION

A MEMBER:—Is the fluctuation in the curve shown in Fig. 9 due to the inertia of the instrument?

C. F. KETTERING:—There is no question that the curve is a composite of a set of conditions. In other words, you simply strike a condition during combustion which is not dissimilar to taking a plank, sticking the end out over the beam, pulling the end down and letting it wiggle.

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Part of that may be due to the inertia of the indicator, but nevertheless the different kinds of fuel will write their names down in fairly good shape. We know that the fuel in there changes its constants, whatever they are.

H. L. HORNING:—I agree that the vibrations are more characteristic of the fuel than of the inertia of the instrument; although our instrument is supposed to have great inertia, the change of fuel has more to do with it. I will say, further, that the fuel and air have much to do with it and so has the temperature; it is primarily a chemical phenomenon.

THOMAS MIDGLEY, JR.:—I agree with Mr. Horning; the vibrations change with the mixture.

A MEMBER:—What does benzol do?

MR. MIDGLEY:—It gives a different characteristic, a smoother one, with a flat top on the curve.

A MEMBER:—Can you put in some kerosene and some crude oil?

MR. MIDGLEY:—We are now running in some fuel oil. It will take a few seconds to clean out the gasoline that was in the pipe leading to the mixture valve; then we will get the fuel oil there and you will notice that the curve will change very decidedly.

Now it is coming, you see it starting to peak up on the screen. As the engine warms up, this will become very much more intense. You see it is coming up more and more sharply all the time. To save time we will pass right on; the next fuel will be ether. This is extremely volatile. I think this one demonstration will disabuse your minds that knocking is in any way connected with volatility. If the engine is warm enough, we need no ignition to run on ether.

I now wish to show some genuine preignition with no knocking. We will put in some carbon-bisulphide. After the carbon-bisulphide is put in and it begins to get through the mixing valve, notice the early rise of pressure and that there is no knocking associated with this. As the early rise of pressure gets over to the left side of the screen, the engine will spit back through the intake valve, showing that preignition is actually so early with this fuel that it occurs before the intake valve is closed. From this demonstration it is seen that knocking is not associated with preignition.

The engine is now operating on benzol, which is a compound quite different from what we have thus far

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run in the engine, as to its chemical nature. There is no trace of knocking whatsoever with benzol.

Now we are running the engine on alcohol, which is the smoothest burning fuel of any we have.

A MEMBER:—Can you tell us the principal characteristic of alcohol?

MR. MIDGLEY:—The principal characteristic is the smoothness of the combustion, the absolute lack of any indication of knock whatsoever.

A MEMBER:—With what maximum compression have you tried alcohol?

MR. MIDGLEY:—Two hundred and twenty-five pounds.

R. W. A. BREWER:—Do you think if you ran it up as high as 300 lb. compression, you would produce a knock?

MR. MIDGLEY:—No, I think not. I wish to show how we can take the knock absolutely out of fuel oil, while the engine is running. We will keep the spark advanced and everything right up on the engine, full power, proper mixture, everything the same. We will then take the knock out of the fuel oil. The engine has been purposely put out of adjustment in order to make the fuel oil knock in it. We have a special carbureter to run up the power and purposely advance the spark beyond where it belongs. We also have some carbon in the cylinder-head to make the engine knock; the engine does not knock under normal operation.

You can now see the knock coming in on the screen. I wish to take it out for you. You observe that the engine is knocking violently. Now, by adding a drop of this liquid at the mixing valve you will see that the knock has entirely disappeared. That was done with one drop of ethyl-iodide. I will now show the same effect by putting in two drops of aniline; you can see the knock disappear and will appreciate that it was done with a very small amount of material added to the fuel.

MR. KETTERING:—Perhaps I can clarify a few things and so help to concentrate the discussion. This indicator was worked out primarily from the standpoint of fuel studies, simply to see how the fuel worked. It was only about eighteen months ago when we heard some papers read in which the kerosene knock was attributed purely to preignition. The chairman made a very significant remark when he said that perhaps we have not been trying the right kind of thing. That is correct; we found out that what we thought about this was not right. After we had read all the literature we went the other way.

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This indicator was developed primarily for that purpose. It is not intended to be a precision instrument, but is simply something with which we can use the different kinds of fuel and run all day long. It is just something that you can sit and look at that you never saw before.

This demonstration and those fuel diagrams show only some of the work that has been done. We have proved absolutely that volatility has nothing to do with knocking, and have demonstrated that the molecular structure of the fuel determines this. The dropping in of a little bit of ethyl-iodide on aniline was only to show that a very small quantity of material added to the fuel can change the whole nature of the combustion. With regard to the present fuel situation, it is just about like this: someone discovered some three or four hundred years ago that sulphur, saltpeter and charcoal, mixed together, made gunpowder. That was a great invention, but it was three hundred years before anyone thought it possible to determine whether the pressure in the gun barrel was right; then they began to find out it was not right; that black powder was not right. They then made all the various high-explosive powders and a gun today shoots a great deal farther, makes much less noise, and has less recoil. None of these indications, none of these physical things that we have regarded as being essential to a gun, have had anything to do with it. We find that by proportioning the powder right, we get a normal acceleration of the bullet.

Our theories today are just as accidental as black gunpowder; we are using just the fuels which normally come from the simplest type of distillation of petroleum products. We have taken the stuff that has been handed to us, without a question as to whether it is right or wrong. I think it is possible for us to make fuel where it is refined and introduce right into the refining of fuels the anti-knock that is necessary to change that fuel. We cannot influence it by changing the chemical composition at the place of refinement, without trying to do it. So, the thing to do is to find out there how to fix that knock. The indicator enables us to clarify our minds and make the problem more or less quantitative. What we must do is to start at the beginning, recognizing that we have a problem. The fact is that we have two problems, wet and dry mixtures. I could make an experiment right here, refrigerating the air and burning kerosene better with refrigerated air, with the wettest kind

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of a mixture, than can be done with the driest kind of a mixture. You can stop an engine from knocking by refrigerating the air and not reduce the power; in fact, the power will increase. With the ordinary multi-cylinder engine we do not know just what is causing the trouble. We must alter the chemical composition of the fuel. I think that the oil people are doing that. It is within the possibilities that when we meet again a year hence we can burn these lower-gravity fuels. Think what it means to take the knock out of the fuel; the formation of carbon then becomes entirely secondary, the compressions being high enough to burn the normal lower-gravity fuel. If we can stop our former practices and go back the other way, there is no reason why we cannot put the engine compressions up where they belong and use smaller bores.

We have run many engines with insulated piston heads. With an ordinary engine and about 1/16 in. of mica sheet on top of the piston heads we need not care how hot they get. There is never a premature explosion. We can take a lot of liberties with the fuel if we handle it properly. With the sheet described on top of a piston head the engine is almost immune from carbonization, for the reason that carbon deposit consists of two absolutely distinct things, one, a lubricating binder which is segregated from the lubricating oil, and the other, deposited carbon which comes out of the fuel.

Mr. Vincent tried to foul the spark-plugs by feeding too much lubricating oil. If we can change the rate of combustion of the fuel so that we can put the compressions up, we will have simplified the whole problem and the progress of the internal-combustion engine will be unlimited. I am not worried about the fuel situation, if we can avoid clinging to the things which we now have. Kerosene is increasing in price because there are millions of kerosene lamps yet. The electric farm-lighting plants have not been in operation long enough to reduce their number. But there is a cut in there, and the limitations of kerosene oil for lamps are much narrower than those for running an automobile on it. We can take liberties with automobile fuel, up and down, but we cannot do much with the kerosene cut for lamp lighting. We must avoid that and reach down into the fuel-oil cut which is about 50 per cent of the total of the crude. There we can get a quantity of fuel, but we must refine it somewhat differently, so that we can burn out the carbon, etc. It is only by getting together and conferring like this

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that we will solve the fuel problem. When we can write it out on the blackboard in specific units, the problem will be solved, because there are hundreds of persons who can take those individual units and go ahead with them.

With Mr. Vincent's heater many things must be considered. In connection with dry mixture, when you burn gas in a manifold that has fuel and air in it, you have changed the whole nature of the thing; there is the tendency to condense, and the vaporization and other factors are changed. For instance, if we feed water vapor we cannot recondense the water at 212 deg. fahr. A mixture with the exhaust gases plus steam does not condense as it would if with pure steam, for familiar reasons. So that burning some gas in the intake manifold right at the start produces a condition that has to do with distribution, which does not necessarily depend altogether upon the wet and dry element. Mr. Good made some very interesting experiments in this connection a number of years ago and found that introduction of exhaust gases into the manifold modified the combustion. By introducing fuel in a semi-burned condition the fuel knock can be eliminated.

When we think of the things we have not done, we realize that we are fortunate to have developed as much as we have, without knowing about the most important thing, the fuel. The automotive industry is a chemical industry. We have acquired information on every subject except the most important one, which is the fuel.

C. A. ADAMS:—Many years ago in France, Professor Berthelot made an elaborate investigation into the velocity of propagation of combustion in gases. He found that with a given initial pressure and a given temperature of ignition, or we might say vigor of ignition, there is a certain velocity of propagation; if the pressure or temperature is increased, the velocity of propagation is increased; but when a certain combination of pressure and temperature is reached there is an enormous jump in the velocity from about 200 to 2000 ft. per sec. This means a change in the method of propagation and may be visualized as follows: The increase of temperature accompanying combustion causes an increase in the amplitude of molecular vibration; i. e., adjacent molecules approach each other more closely and the combustion is handed on from one to the other more rapidly, until the amplitude of vibration reaches a point such that adjacent molecules actually collide, when the time element of heat transfer

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from one molecule to the next is eliminated and the combustion is propagated substantially at the velocity of the molecular vibration. Under these conditions the combustion becomes a real explosion or detonation, which is the cause of knocking in engine cylinders. It is like a hammer blow, as compared with the soft push of the normal combustion.

For every mixture there is a particular clearance below which the compression is sufficient, with the ordinary vigor of ignition, to produce knocking, i. e., a detonation, without preignition. In fact, this is the factor which determines the proper clearance for each type of fuel, since on the score of efficiency it is desirable to have the maximum compression possible without knocking.

Information is already available as to the critical temperature-pressure relations at which detonation takes place in certain gases and vapors, but not in many of the fuels now in use or in contemplation for internal-combustion engines. Is this not an opportunity for conducting research which would be of great value to the engine designer, the results of which would allow engines to be really designed rather than to be just allowed to happen? There are many other considerations affecting design, but this is certainly of fundamental importance and worthy of study.

Mr. Kettering is absolutely right in his estimate of the importance of research and I am glad to see that the Society is beginning to appreciate that importance. We will probably find that it will pay to start such research work, with a study of existing literature in the pure science side of the subject. We may find much valuable information already worked out by scientists who had no thought of its application to the design of internal-combustion engines.

P. L. SCOTT:—We have been working with a type of engine in which carbureter and ignition systems are not used, and have had some very astonishing results in the behavior of fuel, when admitted to the cylinder only when we wanted combustion to start. We have secured as many as ten waves of combustion, and by a simple change have stopped that entirely. On other occasions we have taken two widely-different fuels and been able to produce violent knocking and a number of waves on the indicator card in each case; then, by another change in the manner of admission of the fuel, we have reduced

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the phenomenon. This shows that there is a very wide field for development in this direction. The compressions are very low compared to Diesel-engine practice. The compressions that were used run as low as 200 lb. per sq. in., and the injection pressure of the oil fuel has run as high as 10,000. Has the speaker ever found waves continuing for more than five lengths on any specific card, or found as many as ten waves on a card?

H. C. GIBSON:—The greatest value of this lecture on indicators may be in impressing upon the minds of those who have looked upon the indicator as something of a nuisance, something to be avoided because of its complications and difficulties, the ease with which we can get indications of what is happening inside of the cylinder. After all, that is exactly what we have to do. We are today tending more and more to the division of the power among a large number of cylinders. Every time we add a cylinder we add another team-mate to the crew we already have, and we must investigate the qualifications of each member of the crew. If we merely take the aggregate performance of those members, we get an extremely poor answer as to performance. So it is with the dynamometer or with tests up a hill with a car; we have obtained only the results of the combined, not the individual effort. If we make a change of design or accessories, we perhaps get a result whereby 75 per cent of the cylinders give a better effort, while the remainder give a poorer one; but the net is 10 per cent better, the overall advantage satisfies us, and we let it go at that. If we investigated each member of the team, we could develop the operation of each cylinder to maximum advantage. I feel that every manufacturer of internal-combustion engines ought to be equipped with apparatus of this character for that purpose.

MR. MIDGLEY:—I have a photographed card that I would like to show in reply to the query about having more than five wave lengths. With regard to investigating fixed gases and the introduction of acetylene, we have never done that, but we have made fixed gases knock by merely raising the compression. The relationship between volatility and knocking is off the indicator subject, but it has been investigated with the indicator, and we found that in the same homologous series there is an increase of knocking with the decrease of volatility, but there exists no relationship in volatility between different chemical series; as we have reason to expect, we

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do not find when we get down to where we have nothing but fixed gases to deal with, that we can get rid of the knock.

A MEMBER:—Does that pressure-time diagram tell any more than that the pressure is greater or less?

MR. MIDGLEY:—Not a thing more; it simply tells whether it is greater or less than the admitted pressure.

DR. H. C. DICKINSON:—It was thought that in a general discussion of indicators it would be very desirable to have a paper covering all that is new on the subject, and so a description of the Bureau of Standards' indicator was given by Mr. Midgley.

As to the reason for adopting this type of indicator, about two years ago we found it necessary to devise some means for getting records without getting near the engine. There are two reasons why the aircraft engine presents a problem that no other engine has presented, and one of these I will discuss briefly. The aircraft engine is light and is usually mounted on a flexible support. Therefore the engine itself vibrates with rather high accelerations. This makes it very difficult to mount any recording mechanism which must be rigidly connected to the engine. Although the difficulty might be overcome, there is another difficulty connected with the design of an indicator for a light engine which we have also overcome in this instrument. This is a more fundamental difficulty and one which, so far as I know, has not come into the literature.

Through the top of a cylinder-head, surrounded by a water-jacket and an outer wall, we insert an indicator with a piston or some moving part. The indicator piston has considerable weight and to reduce inertia effects it is necessary that the range of motion which actuates the recorder be very limited. Therefore we have a support rigidly mounted on the cylinder-head and a rather heavy moving part, the piston with a recording device of some sort which magnifies the relative motion between this support and the free piston one or two hundred times. This is very good as long as the cylinder-head itself is rigid enough, but suppose we consider the Liberty cylinder, for instance, where the thickness of material is cut down; then, whenever anything unusual such as a knock occurs in that cylinder, of course this cylinder-head itself flexes with very high velocity. Therefore the flexing of the head carries the supposedly solid support of this piston device with it and allows the piston to

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remain more or less stationary, acting in the same way as the seismograph. This effect probably occurs in the very violent vibrations which take place during knocking at least, and is perhaps also due to flexing of the cylinder-head under normal explosion pressures. I believe that these motions are not of sufficient magnitude to be of any consequence in the cast-iron cylinders which we usually encounter, but in very light constructions they are certainly a mechanical difficulty that has to be guarded against. In planning this design of indicator we must overcome that difficulty by replacing the piston by a very light diaphragm supported by corrugated plates, which are not only perforated but turned out in annular rings so that the only bearing surface of the diaphragm is represented by these rings, the other portions being undercut. There is very little contact between the diaphragm and the support, and yet the support is sufficiently good that a diaphragm 0.002 or 0.003 in. thick will withstand 600 or 700 lb. pressure and be sensitive to within 0.1 lb., or 2 or 3 mm. of mercury, at pressures down around 10 lb. vacuum.

In ordinary operation two things can be done with this indicator; we can use it with a telephone receiver and a pressure gage, or as an automatic plotting device with a cylinder rotating at crankshaft speed, using an ordinary indicator spring and pencil arm with an electric spark, so marking a paper on the revolving drum to record the steady pressure applied to the upper side of the diaphragm. For public demonstration we have substituted for the telephone a high-power announcer, and we have substituted for the pressure gage the working parts of the pressure gage, namely, the bourdon tube with a mirror attached to it, which throws a spot of light upon the chart, so that the pressure scale can be seen directly on the chart and the contact made in the telephone receiver can be heard.

When the pressure in the cylinder is lower than the pressure applied above, the electric contact in the telephone circuit is broken and nothing happens. When the pressure in the cylinder is higher, there is a contact between the diaphragm and the electrode in the telephone circuit; and if the one-point timer, which is also in the circuit, makes contact at any time during that portion of the stroke during which the diaphragm is in contact with the upper support, there will be a click in the telephone receiver. Therefore the method of getting the pressure

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at any particular point is to first set this timer at any desired point, say at dead center; we then vary the pressure over the diaphragm, first increasing it until the clicking begins to become irregular, that is, until we get an occasional break in the periodic ticking in the telephone. This is the lowest pressure which occurs at that point in the cycle; we then continue to raise the pressure until the clicking entirely ceases. That represents the highest pressure which occurs at that point in the cycle. We will now demonstrate this.

First we intend to show the range of maximum pressures which occur. This engine is adjusted so that it is operating very irregularly; therefore there will be a very wide range over which the maximum pressures occur. We shall not attempt to use anything except gasoline and will show the method of getting the pressure which occurs at some specific point in the compression or explosion strokes of the cycle. Then we will plot a diagram which I think will prove very useful with this device, a low-pressure card of the intake or exhaust or compression stroke, as desired. The electrical current is now passing through the diaphragm.

HERBERT CHASE:—What is the object of the central hollow tube at the cylinder connection?

DR. DICKINSON:—The object of the hollow tube or the series of small tubes is to cool the gas to some extent on passing through the water-jacket before it reaches the diaphragm. That is not essential, but it was incorporated in this design.

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COMPOSITE FUELS

By Joseph E Pogue[1]

The progressive decrease in the volatility of gasoline due to the insufficiency of the high-volatility supply has developed a problem of efficient utilization of internal-combustion-engine fuel that requires coordination between the engine and its fuel and a technical as well as economic adjustment between supply and demand. The three channels through which this adjustment tends toward accomplishment are stated and commented upon, consideration then passing to the three main resources from which the components of composite fuels can be drawn. Regarding benzol and alcohol for use as engine fuel, neither can be produced in sufficient quantities in the near future to replace gasoline and this whole field needs greater research attention, but the danger of thus obscuring the necessity of engine adaptations to secure higher thermal efficiency and lessened dependence upon specialized fuels is also pointed out, these being essential elements in a fundamental solution of the engine-fuel problem.

In the past year considerable attention in the automotive field has turned to the relation between the internal-combustion engine and its fuel. The rapid rise of automotive transportation in recent years has been the occasion of a country-wide change in the volatility of gasoline, which has attracted widespread interest and raised the problem of better fitting the fuel to the engine, or vice versa, or else striking a compromise between the two.

The problem noted above has been frequently spoken of as one of fuel shortage, actual or prospective. There is no danger of a *material* shortage of automotive fuel in the United States for some years to come, although an *artificial* shortage can readily be created if engine and fuel are permitted to develop at cross-purposes. Expressed in other terms, our liquid fuel resources, lavishly and wastefully drawn upon though they have been, are still sufficient to sustain the needs of the immediate future, if only the products are efficiently utilized. Efficient utilization means coordination between the engine and its fuel, a technical as well as economic adjustment between supply and demand.

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As the matter is shaping now, there are three avenues through which this adjustment is tending to come about

(1) The production of a growing quantity of synthetic gasoline from the heavier oils, through the so-called cracking processes of distillation
(2) Adaptations on the part of the engine to accommodate the efficient utilization of less volatile gasolines and heavier oils
(3) The development of composite fuels or blends, which permit the enlargement and possibly the improvement of the fuel supply, through additions of material not suitable or sufficiently bountiful alone to be of consequence

The future of any one of these three expedients for furthering the advance of automotive transportation depends upon the course of development in respect to the other two, and the final outcome may be expected to be the resultant of numerous factors which cannot be wholly appraised in advance. Not the least of these is the extent to which the whole matter is brought under scientific control by far-sighted and constructive efforts on the part of the fuel and automotive industries acting in common. A final adjustment may be reached through the outworn method of trial and error or through the more modern means employed in meeting tangible engineering issues.

Composite fuels are by no means a new element in the fuel situation, even in the United States. Indeed, much of the gasoline marketed in this country today is composed of straight-refinery gasoline blended with gasoline made in pressure stills, or with casing-head gasoline recovered from natural gas, together with petroleum distillates that were formerly sold as naphtha or kerosene; and even some gasolines are being modified through the addition of benzol. Casing-head blends alone have succeeded in adding about 10 per cent to our total supply of engine fuel. Composite fuels, in which not only distillates of petroleum origin but benzol, coal-tar oils, alcohol and even other chemical products play a part, have of course long been in use in Europe, and some of these met with considerable expansion during the war, especially in Germany. In the past 12 to 18 months, fuel blends containing benzol or alcohol have also come into qualitative, if not quantitative, prominence in the United States, thus drawing attenion to the possibilities of their future importance in this country.

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Sources of Composite Fuels

The resources in sight from which the components of composite fuels may be drawn are mainly three in number

(1) Crude petroleum, including its successor, shale-oil
(2) Bituminous coals, which are capable of yieldnig tar oils, benzol products and other hydrocarbons when subjected to by-product distillation
(3) Organic products rich in sugars, starches or cellulose, especially waste products of organic origin, from which oxygenated hydrocarbons such as alcohols and ethers can be manufactured, chiefly through the aid of bacterial fermentation

As regards the quantity of raw material available, the United States is bountifully endowed in all three respects. Since, however, an extensive and highly organized industrial agency of fabrication and distribution must stand between these resources and the utilization of their fuel potentialities for automotive power, the development of composite fuels becomes dependent not only upon the conditions controlling the growth of the oil-refining industry, the coal-refining industry and a group of activities which may be termed the fermentation industry but also upon the interplay between these three interrelated activities.

The oil-refining industry is the largest, most firmly established and highly developed of the three, and its capacity and industrial ability may be rather briefly dismissed as being sufficiently in mind. This industry turns out four products of major importance to modern civilization, gasoline, kerosene, fuel oil and lubricating oil, not to mention a host of by-products; and its output of gasoline, in consequence, is intimately tied up with the production of joint products demanded by needs scarcely less pressing than automotive transportation. Thus, gasoline has become a product which must be produced, if the market for other oil products is to be supplied; while the oil industry, in addition, has established country-wide machinery for distribution. These economic facts have a direct bearing upon the manner in which composite fuels can be expected to develop; they make it probable that composite fuels, if found desirable, will ultimately be purveyed dominantly by the oil in-

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dustry rather than by outside activities, under whatever auspices the initial developments take place and without any reference whatsoever to matters of financial control.

The coal-refining industry has thus far been slow of development in the United States. To date it has succeeded in involving only about one-twelfth of the bituminous coal brought into use, approximately eleven-twelfths being still consumed in the raw state; the coke industry and the artificial gas industry are responsible for the advance noted. The production of benzol and related hydrocarbons is mainly dependent upon the progress attained in coal refining.

Up to the present, most of this progress has taken place in the coke industry, where by-product practice is gradually superseding the so-called beehive process, in which benzol and other by-products are not recovered; benzol is now being produced in connection with about half of the coke manufactured in this country. In 1918 the output of benzol from this source was 44,000,000 gal. With by-product practice throughout the coke industry, the output would have been but doubled, scarcely 2 per cent of the quantity of gasoline produced in 1919. The coke industry, therefore, can at best be expected to furnish a quantity of liquid fuel wholly inadequate to have broad significance, except in so far as it may be used as a blending agent to give desirable qualities to other liquid fuels obtainable in larger quantities.

The artificial gas industry was responsible in 1918 for the production of 4,400,000 gal. of benzol, recovered from gas plants operating with by-product recovery. The entire artificial gas industry, however, consumes less than 2 per cent of the country's supply of bituminous coal, and as long as this activity retains its present relatively stationary status the quantity of engine fuel to be expected from this source is practically negligible. There is a possibility, however, that the next few years will see the upgrowth of municipal fuel plants and centralized power stations, operating with by-product recovery, which will give a new source of benzol of greater potential significance than the coke industry in its entirety. Such developments, on the other hand, must of necessity be slow; and should benzol eventually be extracted from the bulk of our bituminous coal, it is evident that, on a basis of 2 to 3 gal. per ton, the supply will even then fall far short of a dominant position as a source of automotive power.

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Possibilities of Alcohol

The fermentation industry, notably the branch having to do with the manufacture of industrial alcohol, has been strongly stimulated by war demands, and industrial machinery is now available for the production of considerable alcohol for fuel purposes. The arrival of prohibition has also freed a large equipment from other duties, which might in part be devoted to a similar end. There are serious handicaps of a sentimental nature, however, which tend to bind the manufacture of industrial alcohol with governmental restriction harmful to proper progress; although the war-installed equipment and the cheapness of the requisite raw material may be sufficient to balance these drawbacks.

Alcohol alone can be used to advantage only in engines especially adapted to this fuel, but various mixtures of alcohol, benzol, gasoline or other petroleum distillates and other materials have given promising results. It is of great significance from an economic standpoint that alcohol, benzol and the lighter petroleum distillates such as gasoline and kerosene can readily be rendered miscible. It is probable that alcohol, like benzol, will not come into widespread use as a single fuel, but has a broad significance, for the present at least, only as a blending agent in connection with liquid fuels obtainable in larger quantities.

The quantity of alcohol which will be produced in this country in the immediate future is much more difficult to forecast than in the case of benzol. The United States in 1916, 1917 and 1918, turned out about 50,000,000 gal. of denatured alcohol each year, having jumped from an output of 14,000,000 gal. in 1915 under the stimulus of a demand born of munitions requirements. Much of the industrial alcohol under manufacture today is made from sugar molasses and waste sulphite liquor; while garbage, fruit wastes and ethylene from coal-distillation plants have been suggested as supplementary resources. While the alcohol capacity of the country cannot be closely estimated without a special investigation beyond the scope of this article, the conclusion seems inevitable that for some time to come the available supply of alcohol will bear a close quantitative analogy to benzol, the two combined bulking small when compared with engine-fuel requirements which will approach 5,000,000,000 gal. in 1920.

On the whole, therefore, it may be concluded that ben-

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zol and alcohol hold somewhat analogous positions in respect to the supply of engine fuel. Neither can be produced in sufficient quantities in the near future to replace gasoline; both have interesting possibilities in the direction of improving the character of the fuel supply in respect to present engine types. This whole field is undeveloped and stands in need of more research attention than has been accorded it.

Higher Thermal Efficiency of Engines

Composite fuels, while holding out the possibility of improving the adjustment now obtaining between the fuel and the engine, present also the danger of obscuring for a time the necessity of adaptations on the part of the engine in the direction of higher thermal efficiency and lessened dependence upon specialized fuels. Composite fuels, if found to fulfill their initial promise of advantage in utilization, can be developed by the oil industry or, in a more limited manner, by outside agencies; but they can be more readily developed on a large scale by the oil industry, because of its control of working channels of distribution.

In conclusion, while nothing revolutionary may be expected in the way of composite fuels that will displace gasoline, there may come into evidence a steady trend toward a fuel supply of petroleum origin carrying small quantities of other materials, chiefly benzol and alcohol, which will facilitate utilization in the present types of engines. It would be unfortunate, however, if this outcome resulted in a relaxation of the efforts for higher thermal efficiency and for lessened dependence upon specialized fuels, which still remain essential elements in a fundamental solution of the engine-fuel problem.

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TENDENCIES IN ENGINE DESIGN

By L H Pomeroy[1]

War service demanded that gasoline engines be absolutely reliable in minor as well as major details of construction; lightness of construction was second in importance. The war scope of the gasoline engine was so wide that engineers were forced toward the solution of unexpected and unrealized problems and a vast amount of valuable data resulted. This information includes recent determination of the quantitative nature of the factors governing thermodynamic performance in respect to mean effective pressure, compression ratio and the effect of volumetric efficiency; mechanical performance in regard to mechanical efficiency and internal friction; and engine balancing. The problems of the past five years of intensive gasoline-engine experience, thus brought under critical survey for the first time, are discussed in the light of recent developments and a reexamination made of designers' existing practice to determine the trend of design regarding the obtaining of absolute mechanical efficiency; the application of modern views of gasoline engine thermodynamics; improvements in mechanical efficiency, engine balancing, carburetion and capacity to utilize low-grade fuels; the principles of light-engine design; and clean-cut design in general.

At the moment, engine design is developing in the light of experience gained in the past five years of war, and according to the economic demands resulting from the world shortage of materials arising from the same cause. From the engineering point of view, the war turned half the world into a gigantic experimental shop in which the result was the only thing that counted, without regard to the cost of obtaining it. All services demanded that gasoline engines should be absolutely reliable in minor as well as major details of construction. Trucks and cars, for instance, had to be operated virtually independently of a service station, and under conditions where life might be endangered as much by a defective spark-plug as by a broken crankshaft. This imperative demand for absolute reliability showed very clearly the importance of detail design and manufacture. Cars and particularly

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trucks that were defective in some more or less unimportant detail for ordinary service were discarded during the war for these slight defects.

Second to reliability in importance came lightness of construction, either absolute or in relation to thermal efficiency, as in aeronautic engines, and of equal importance was thermal efficiency *per se*, with the capacity to use low-grade fuels. It is not suggested that all of these points were of equal importance on all kinds of gasoline engines, but some applied to all engines, and all applied to some.

The scope of the gasoline engine during the war was so wide, the necessity for its use so imperative, that engineers have been literally forced toward the solution of problems hitherto unrealized. Arising from these developments a vast amount of information is available, which he who runs may read. Airplane, touring car, truck, tractor and tank have been developed or stimulated by the test of war. The history of previous civilization, in which progress would have been delayed by thousands of years had a League of Nations been established 1000 years ago, repeats itself so that today we are in a position to take stock of the accumulation of war experience for the betterment of the gasoline engines of tomorrow. The engineer engaged upon a new design has a wealth of knowledge at his disposal, so that, although there have been but few variations from type due to the war, it is possible for him to design with a sureness of touch and to achieve results out of all proportion to the apparent difference between a new design and that of a few years ago.

The factors governing thermodynamic performance in respect to mean effective pressure, compression ratio and the effect of volumetric efficiency, have been recognized and known for many years, but the quantitative nature of these factors in gasoline engines running at high speeds has been only recently determined. Similarly, there have been many contributions to our knowledge of the mechanical performance of gasoline engines in respect to mechanical efficiency and internal friction, but the quantitative nature of the frictional effects arising from each organ is a product of recent research. Engine balancing has also been the subject of much attention, as engine speeds have been gradually raised to enable the high-speed characteristics of the gasoline engine to be fully exploited.

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In general, the result of the past five years of intensive gasoline engine application has brought a host of problems under critical survey for the first time, and of no less importance is the re-examination of the position in respect to many designers' articles of faith that are crystallized in existing practice. It is, therefore, proposed to discuss the trend of design in the light of recent developments of the following:

(1) The effect toward obtaining absolute mechanical reliability
(2) The application of modern views of gasoline engine thermodynamics
(3) Improvements in mechanical efficiency
(4) Improvements in engine balancing
(5) Improvements in carburetion and the capacity to deal with low-grade fuels
(6) The principles of light-engine design
(7) Cleanness of design

Mechanical Reliability

The aim of the engineer during all time has been to overcome the weakness of the materials he has been forced to use and the defects arising from his own ignorance and carelessness, to say nothing of the ignorance and carelessness of others. The advent of the automobile, its immediate appeal to a pleasure-loving public and its enormous convenience and economic application, created a demand which it is not unfair to say killed or seriously wounded for some time the ideals of the engineer. The truth that the best is the cheapest, which has been demonstrated over and over in other engineering fields, was temporarily lost sight of and good engineering was subordinated to the whims of the purchase, production and sales departments. The result is well known. Many firms in both Europe and America have had to clean house and set out to incorporate good engineering, apparently at the expense of production, to find ultimately that accuracy and quality of machine workmanship were not only compatible with cheap production but reduced production cost, and that a few hours spent on the drawing-board were repaid infinitely by shop economies. The combination of good design, workmanship and material, reflects itself immediately in the satisfaction of the purchaser and the reduction of service charges and maintenance. It is safe to say that at no time in the history of the development of the automobile have the services and possibilities of the engineer been

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as widely realized by commercial administration as today. The underlying reason is, as usual, a matter of dollars.

The proportion of the catalog price chargeable to brains and labor is but a small one, at the outside not in excess of 20 per cent; the item chargeable to materials is at least twice this, and further, the difference between the cheapest and most expensive material is a still smaller percentage of the whole. The remaining 40 per cent or so of the total is sales cost and profit.

If there is one thing certain, it is that a bad car is not salable very long, even by the most skilled sales department; and, if we could imagine such a thing as a perfect car, the probable increased cost of labor, material and factory cost generally, would be amply saved in a reduction of sales charges. While the latter are something like twice the amount paid for the whole of the services used in producing the car, the argument is demonstrably fallacious that reduction of cost by reduction of quality is sound commercially. It is, therefore, reasonable and economical that, in the attainment of a high degree of mechanical reliability, the engineer should not be unduly hampered in respect to the cost of production and should be given free scope for living up to the tradition of being able, not only to make for $1 what any fool can make for $2, but to produce a result which allows any fool to sell for $2 that which previously only a spellbinder could sell for $1.

I have had the honor and pleasure of being conducted over many American factories during my stay in the United States and have seen with great pleasure the vindication of principles I have held for many years in relation to cost of production. By sheer manufacturing skill and enterprise, work of the first quality is produced, complex parts seem to have no terror for the production department and any rational increase in the complexity of design does not appear to be a consideration in arriving at a desired result. The engineer is far less limited here than in Europe in attaining his ends, and for this reason the goal of complete mechanical reliability is well within sight when an automobile will be as reliable as a watch.

What, then, are the lessons to be learned from the past few years in this respect? Possibly the first is that of the importance of material, and particularly the correct heat-treatment of steel. Aeronautic engine development has shown what can be done in these respects. The gasoline engine may be considered structurally as a combina-

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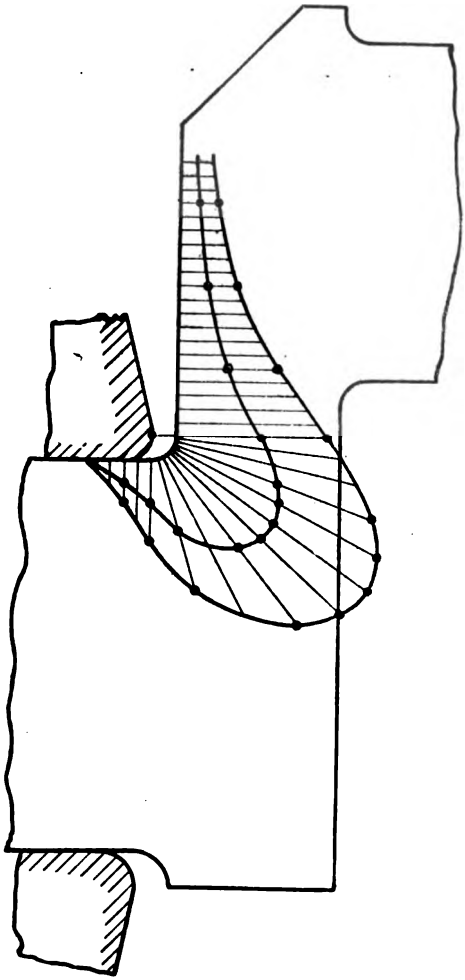

FIG. 1—STRESS DISTRIBUTION IN TRANSPARENT MODEL OF A CRANKSHAFT

tion of bearings and supports therefor. A large percentage of mechanical troubles are due to failure or wear of the bearings and distortion or fracture of their supports. The importance of choice of material in respect to bearing surfaces is almost as important as the lubrication system upon which they depend for their successful working, while rigidity of construction is a function of the supports and the correct geometrical disposition of

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the material thereof. As an example, piston-pin design can be taken. The older type of piston-pin for an engine of say 4-in. bore had a projected area of about 7/8 by 2 in. and gave trouble even then. The type of piston-pin in use on the Ricardo tank engines of 5 5/8-in. bore had a projected area of 2 sq. in., an intensity of loading approximately two and one-half times that stated above and gave absolutely no trouble. This result was obtained primarily by a rigid support of the piston-pin and by first-class case-hardening.

Allied to this aspect of reliability has been the recognition of the great weakness imposed upon mechanical details through sudden variations of section and consequent mal-distribution of stress. Professor Coker, of London University, has evolved a means of visualizing by polarized light the stress distribution in transparent models of loaded members. Fig. 1 illustrates the stress distribution in a transparent model of a crankshaft, showing the high intensity of stress in the inside crankshaft fillets compared with the average stress and the imperative necessity for considering such local distribution of stress in parts of small dimensions as are commonly used in gasoline engines. The two curves shown are a measure of the stresses produced by a bending moment of one and two units respectively, the perpendicular distances from the contour of the crankshaft to the curves being a measure of the stress produced.

In 1914 I was largely responsible for the design of some very high-speed engines, running up to 4000 r.p.m., in which the crankshafts were to all appearance of ample stiffness and strength. Experience showed, however, that it was not until the crankshaft fillets were increased from 3/16 to 3/8-in. radius that reliability was attained. Fig. 2 illustrates the method in which the 3/8-in. radius fillet was obtained on crankshafts already machined with the orthodox 3/16-in. fillets. Probably 75 per cent of mechanical failures arise through a lack of appreciation of the stress distribution and the cultivation of a keen eye in this respect is of inestimable value; much more so than the capacity to use mathematical analysis, important as this is in the determination of general stresses.

Passing from structural reliability pure and simple, or the ability of the engine to withstand the forces set up within it, we come to the problems connected with temperature, fuel and lubrication. The last two are so inter-

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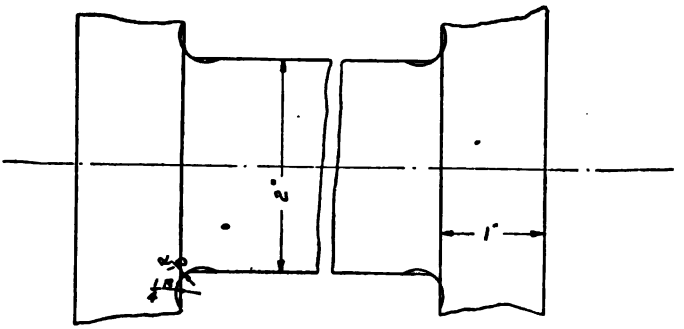

FIG. 2—METHOD OF OBTAINING ⅝-IN. RADIUS FILLET ON CRANKSHAFT MACHINED WITH 3/16-IN. FILLET

woven that their relationship will be discussed in a later section. In respect to temperature problems it has been said that internal-combustion engine cylinder-design combines the problem of the hydraulic press with that of the boiler tube. It is necessary for a cylinder to withstand considerable pressure and also to be a first-class heat conductor. The one calls for thickness of metal, the other for thinness.

Fortunately, in gasoline engines of small size very little difficulty arises. The conductivity of the metal of which the cylinder is made is so overwhelmingly greater than the film resistance of gas and water on each side of it, that the temperature gradients in the metal are not sufficient to cause trouble. The heat resistance of cast iron ¼ in. thick is only about 1/100 of the resistance to the entrance of heat on the gas side and its emission on the water side. Hence, the disappointment arising in the use of aluminum for air-cooling cylinders, the advantage conferred by the high conductivity of aluminum being completely masked by the small proportion which the heat resistance of the cylinder wall itself bears to the whole. In the case of pistons and valves, however, the position is very different. In these the heat has to be conducted some considerable distance before it is dissipated, so that the conductivity of piston materials is very important. Principally for this reason the aluminum piston has found a ready demand. The advantages of aluminum pistons in relation to the reduction of reciprocating weight will be discussed later. Here it is sufficient to point out the great advantages of the aluminum piston from the point of view of the reduction of piston temperature. Some years ago Professor Hopkinson made experiments to

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determine the temperature of cast-iron pistons in a Siddely engine and found that this approximated 500 deg. cent. (932 deg. fahr.) at full load. Today the temperature of an aluminum piston of 7-in. bore at 1200 r.p.m. does not average over 200 deg. cent. (392 deg. fahr.). This achievement sets free possibilities for increasing the speed of large engines and of literally revolutionizing the design of the moderate-sized heavy internal-combustion engine on the one hand, and of allowing a still further increase in the speed of revolution of the small engine on the other.

Engine speed is no longer limited by considerations of piston temperature. For the same reason the designer can adopt large-bore cylinders with impunity if he so desires. As an example of progress in this direction to date may be cited a British six-cylinder engine developing 700 hp. at 1200 r.p.m. from cylinders of 7-in. bore and 11-in. stroke.

Although not related to temperature problems, the mention of aluminum calls for a remark upon the possibilities arising from the forged aluminum connecting-rod. Just as the aluminum piston permits an indefinite increase of piston size and revolution speed from the thermal point of view, so the aluminum connecting-rod removes another limitation of engine speed, that due to bearing pressure caused by the inertia effects of the big end of the connecting-rod and the inherent unreliability of a soft bearing metal under heavy loading. In my opinion the forged aluminum connecting-rod marks one of the greatest advances in the detail improvement of the gasoline engine and will have a very marked effect upon the trend of design, by no means limited to the connecting-rod itself.

Reverting to temperature problems, mention must be made of the advances in the materials from which valves are made. The use of aluminum for valves has not been developed commercially, although the aluminum valve is within sight. On the other hand, steels have been developed, notably nickel-chrome, cobalt and tungsten alloys, which successfuly resist the temperatures to which they are subjected. A further development has been that of the water-cooled exhaust valve, the cooling effect being obtained by drilling the valve, filling it with water and permanently plugging it. This practice is the invention of Sir Henry Fowler of the Royal Aircraft Factory in England. Although the evidence in support of the claims

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made in respect to a reduction of exhaust-valve temperature seems incontrovertible, the reason therefor is not easy to see. It seems inconceivable that the introduction of water, in itself an exceedingly bad conductor of heat, in place of steel can aid the conduction of heat from the head to the valve-stem. It also seems inconceivable that any convection effects which may be set up in the water can be as efficacious as direct metallic conduction, from the point of view of heat transference. It is obvious that the high specific and latent-heat properties of water can exercise their influence in heat absorption for only a short period. The authority behind the device, however, and the experimental evidence of its utility call for its description.

The various factors so far mentioned, namely, materials, stress distribution, rigidity of bearing supports, the use of aluminum pistons and connecting-rods and heat-resisting steels, are to be regarded as affecting reliability not only in the light of their application to existing designs, but also as to their influence upon the broad principles of gasoline engine design and construction. The ability of any engine to resist wear-and-tear is largely a function of the speed at which it is run. I showed many years ago that an engine would wear out far more quickly if driven by a belt at say 1500 r.p.m. than if it ran at this speed under load. Reliability apart from heat considerations is, therefore, largely a question of resistance to inertia effects, the working fluid pressures being of secondary importance. From this point of view there is considerable justification for the high-speed multi-cylinder engine of the eight and twelve-cylinder types, on account of the reduced inertia effects arising from subdivision of the working units.

The secondary unbalanced forces, for example, in an eight-cylinder engine are but 1.4 times those of a four-cylinder engine with the same size and similarly designed cylinders. For a given stroke the horsepower at any given speed is proportional to the square of the bore, while the mass of the piston is proportional to some power between the square and cube of the bore. It follows that the inertia forces in a four-cylinder engine are considerably higher per square inch of cylinder area than in an eight-cylinder engine of the same capacity running at the same speed. The same reasoning applies to the valves and tappets, where the inertia effects are of first importance. Other things being equal, it is fair to say that there is a greater potential reliability in an

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eight than in a four-cylinder engine of the same capacity. The actual practical differences arise principally from secondary influences caused by human error and are not fundamental.

In the light of the developments outlined above, however, the problem is entirely changed. The use of aluminum pistons enables the inertia forces in a four-cylinder to be reduced very considerably below those in an eight-cylinder engine of the same capacity, using cast-iron pistons, and if aluminum connecting-rods also are used the wear-and-tear on the engine is cut literally in half at the source. Since the bearing pressures are thus reduced, the desirable rigidity of the supports is much more easily obtained, so that the improvement resulting is cumulative.

The providential coincidence that the lightness of aluminum is accompanied by high thermal conductivity is in its way as far-reaching and remarkable as the fact that two of the most important discoveries in relation to the development of the automobile, namely, the pneumatic tire and aluminum, arrived at the same time in history and were utterly unrelated to each other.

The designer of today has, therefore, an enormous unexploited field for the application of his experience and ingenuity. He is far removed from the limitations of only a few years ago, and the next decade should be productive of results which are startling both technically and economically.

Modern Views of Gasoline Engine Thermodynamics

Insofar as basic principles are concerned, the science of thermodynamics in its relation to internal-combustion engines generally and gasoline engines in particular is where it was. There have, however, been important contributions to our knowledge of the mechanism of combustion and the working properties of a mixture of gasoline and air. Chief among these is the recognition by automobile engineers of the phenomena associated with turbulence in their effect upon the gasoline engine, the investigation of the limit to which compression can be raised and the ancillary problem connected with so-called detonation or "pinking."

In 1912, Sir Dugald Clerk showed diagrams at the meeting of the British Association, illustrating the vital importance of turbulence in relation to the speed of ignition and, therefore, to engine speed. One of his diagrams

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is reproduced in Fig. 3. These diagrams were taken by an optical indicator from an engine in which a trip-valve gear was fitted so that the working charge could be retained within the cylinder and alternately compressed and expanded for a few revolutions before being ignited. The slow rate of ignition after two expansion and three compression strokes is clearly shown in the diagrams, proving how essential it is that the gas shall

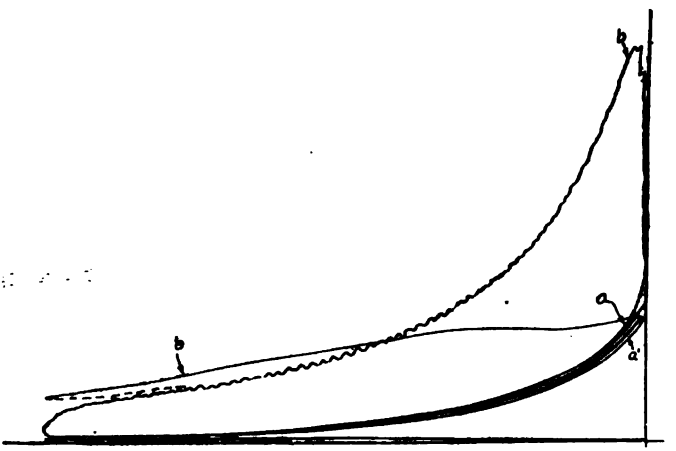

FIG. 3—DIAGRAM SHOWN BY SIR DUGALD CLERK IN 1912 INDICATING THE RELATION OF TURBULENCE TO SPEED OF IGNITION

be in a state of violent motion at the instant of ignition. This state arises in the ordinary gasoline engines from the high velocity of the mixture passing through the inlet valve. The generally accepted opinion for many years has been that so long as the gas velocity is not less than 130 ft. per sec. sufficient turbulence is produced. I consider that the specification of valve area in terms of gas velocity is distinctly misleading. The effect of gas velocity upon turbulence must obviously be related to the revolution speed, for the reason that, although the turbulence produced by a gas velocity of 130 ft. per sec. is ample for rapid ignition at 1000 r.p.m., it might be very inadequate at 2500 r.p.m. It is necessary to specify valve area rather as a percentage of cylinder volume, however much this may offend the exponents of dimensional theory.

Recent experiments seem to show, however, that there is considerable ignition delay at very high engine speeds with such gas velocities, and that it is important to

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stimulate turbulence by all possible means. By so doing three ends may be attained.

(1) Reduction of the tendency to detonate, due to non-homogeneity of the working fluid; in other words, more thorough mixing of air and gasoline vapor inside the cylinder

(2) The ability to increase engine speed and still maintain high mean effective pressures

(3) Higher thermal efficiency due to the ability to raise compressions and subdue after-burning

The chief factors involved, from the designer's point of view, are the shape of the combustion chamber and the size of the valve required to allow for high volumetric efficiency. It is essential that the cylinder be fully charged at high speeds, and also that the inlet-gas velocity be high enough to produce sufficient turbulence for complete and rapid combustion, conditions which it will be readily seen are incompatible.

Some two years ago I conducted an exhaustive series of experiments upon two engines of approximately 180 cu. in. capacity, one with overhead valves, the other with side-by-side valves, to obtain data upon these points.[2] Taking compression pressure as a measure of volumetric efficiency, I found that with inlet-gas velocities of 300 ft. per sec., as good volumetric efficiencies were obtained as at any lower velocity. This was due to the effect of delayed inlet-valve closing, the valves in question closing at 45 deg. after bottom center, thus causing a virtual shortening of the compression stroke. However, as experiments with earlier inlet-valve closing showed but very little improvement in torque, and that only at very low speeds, the practical aspect of the case remains unaltered. I also found that, with the side-by-side valve engine, the results in respect to mean effective pressure and thermal efficiency were far and away below the practical ideal which should be anticipated from the compression ratio used and the high volumetric efficiency obtained. In the case of the overhead-valve engine, the mean effective pressure was some 16 per cent higher than that of the side-by-side valve engine, for the same compression ratio, although the thermal efficiency was not greatly improved. The combustion chamber of the overhead-valve engine, however, was

[2] See *Proceedings* of Institution of Automobile Engineers, 1918-1919.

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far from ideal in shape, due to the use of one large inlet valve and two exhaust valves, so that, presumably, through contact with extended cold combustion-chamber walls, a large and approximately equal percentage of the fuel supplied to each engine was unburned during the explosion stroke in each case, the higher mean effective pressure in the overhead-valve engine being caused by greater turbulence due to the improved inlet-valve location.

In the past, combustion-chamber shape has been regarded almost entirely from the viewpoint of the heat loss to the cooling water during the early part of the explosion stroke, and the experimental and theoretical work done on this subject has gone far to mask the real importance of combustion-chamber design in gasoline engines. Sir Dugald Clerk has shown that in gas engines approximately half the cooling loss occurs in the first 30 per cent of the stroke and the remainder in the last 70 per cent. Gibson and Walker have shown also in experiments with slow-speed engines that the total jacket-heat loss is 18 per cent of the fuel supplied. An analysis by Lanchester of the Gibson and Walker results supports his reasoning that part of this heat loss is constant and depends upon the absolute cylinder dimensions, while the remainder is a constant percentage of the total fuel supplied and is due mainly to internal radiation, the heat loss to the cooling water being less at high speeds than at low speeds at full load. The effect of this reduction in loss at high speeds upon thermal efficiency was, however, in the Gibson and Walker experiments only about 1 per cent, although the jacket loss at 250 r.p.m. was 16 per cent, against 20 per cent at 100 r.p.m. The reason for this is that a large part of the jacket loss occurs in the exhaust stroke and therefore does not affect thermal efficiency.

We have, therefore, in an ordinary gas engine a loss of about 9 per cent of the heat supplied in the first 30 per cent of the stroke, or that part in which the combustion-chamber shape is most important. This is so little as to render considerations of the combustion-chamber shape of secondary importance in respect to the jacket loss and has led more than one designer astray in his search for high mean effective pressures and thermal efficiencies in gasoline engines. In my view, the attitude of indifference of many designers to thermodynamic problems is because the facts of the gasoline engine do not square with the theories of the gas engine, and these are

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largely reconciled if the considerations already mentioned in respect to combustion-chamber design are kept in mind. Briefly, the factors governing combustion-chamber design are first, compact geometrical shape; and, second, provision for adequate valve area.

The strongest argument in favor of the overhead-valve engine is its ability to burn the maximum proportion of the fuel supplied, owing to the compact combustion-chamber inherent in this valve system, the superior orifice coefficiency of the overhead valve being freely granted as against that of the ordinary pocket-located inlet valve. There is reason to believe, however, that a side-by-side valve engine can be designed in which the turbulence effect is even greater than in an overhead-valve engine, so that the extremes may meet. My experiments convince me that for engines of 40 to 60 cu. in. per cylinder a pocket-located valve will allow for a combination of this turbulence without any sacrifice of volumetric efficiency up to 3000 r.p.m., which is high enough for the present. It is significant that, after ten years or more of intensive high-speed engine design, there is no fixed opinion upon valve location, and that the manufacturers with the greatest experience with overhead valves do not use them in touring-car engines. In this connection it must be remembered that the question of side-by-side valve versus overhead valve is not necessarily determined on the grounds of efficiency and power alone. The purchasing public, who, after all, are the final arbiters in the matter, will give short shrift to thermodynamic perfection if this is accompanied by personal discomfort. As the ability of an engine to behave itself perfectly at low engine speeds and to possess great flexibility is not the least of the qualities demanded by the user, it must be pointed out that compact combustion chambers, such as arise naturally in the design of overhead-valve engines, are prejudicial to sweetness of running, particularly at low speeds and part throttle. Not the least virtue in respect to the orthodox side-by-side valve engine is the fact that the film of gas in contact with the comparatively cold walls of the combustion chamber burns during the expansion stroke with a quasi-Diesel effect, so that an indicator diagram taken under these conditions has a rounded top. This largely accounts for the popularity of the side-by-side-valve engine in spite of the deliberate sacrifice of economy and power.

There is room for much experiment along the lines of

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a compact combustion chamber, combined with a design in which the preservation of the cold gas film is realized, so that the best compromise between flexibility, power and efficiency can be obtained. All that can be said at present is that both side-by-side and overhead-valve engines represent opposite extremes, each introducing undesirable characteristics. In the light of recent research, I am inclined to think that it is going to be much easier to make the side-by-side valve engine more efficient and powerful than to make the overhead-valve engine sufficiently flexible. However, the ultimate type may quite conceivably be determined by secondary considerations, such as manufacturing convenience, silence and general appearance.

Improvements in Mechanical Efficiency

The mechanical efficiency of gasoline engines has been investigated by many workers and the records of engineering societies are full of data thereon. As far back as 1907, Professor Hopkinson at Cambridge University measured the mechanical efficiency of a four-cylinder Daimler engine by an optical indicator and one of his assistants, Mr. Morse, evolved the method that is so largely used today of measuring mechanical efficiency by cutting out one cylinder of a multi-cylinder engine and finding the torque exerted by the remaining three. The difference at the same speed between the torque of three cylinders and that of four in a four-cylinder engine is the indicated torque of the non-firing cylinder, thus allowing the relation between brake-horsepower and indicated-horsepower to be measured with four readings. The analysis of frictional losses of gas engines was also investigated by Hopkinson, and those of high-speed gasoline engines by Riedler in Germany, to mention only two of many investigators.

The overall mechanical efficiency of both gas and gasoline engines was found to be remarkably independent of their relative sizes, being about 85 per cent in large gas as well as in small multi-cylinder gasoline engines. Great falling off in the mechanical efficiency of the gasoline engine with increase in speed was, however, apparent.

In my opinion, it is most unfortunate that mechanical losses have to be subdivided into those arising from gas friction and bearing friction, but the definition is too well established to be worth contesting. The gas friction or pumping losses may therefore be discussed first. These, it is well known, arise from the friction due to ports and

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valves, both intake and exhaust. In the normal gasoline engine the gas flow into the cylinder is due to the difference between the pressure in the cylinder and that of the atmosphere. It is also possible to have two engines of equal volumetric efficiency, but in which the work done by the piston in charging the cylinder may be widely different. A late opening and closing inlet valve will give a suction diagram somewhat like Fig. 4. An earlier opening valve (See Fig. 5) will reduce the area of the suction loop very considerably and improve performance to the extent indicated by the difference in the negative work areas.

The combination of decreased gas velocities in inlet valves and manifolds, together with a better understanding of the phenomena associated with the induction stroke, has had a very pronounced effect upon the mechanical efficiency of the gasoline engine at high speeds, which can be counted on nowadays to be well over 80 per cent at 2000 r.p.m., a result obtainable 10 years ago only at speeds well under 1000 r.p.m.

The back-pressure due to the exhaust should also be mentioned if only to point out its relative unimportance owing to the rapid escape of the exhaust gas when the exhaust valve is opened. Further, it is easy to arrange exhaust pipes so that there may actually be a negative pressure in the cylinder toward the end of the exhaust stroke. The all-important point is that exhaust gas under pressure is not trapped in the combustion chamber when the valve closes. With valve areas such that gas velocities do not exceed 300 ft. per sec., the influence of gas friction upon mechanical efficiency is not of much account, nor is it susceptible of much reduction. The frictional resistance of the carbureter itself is usually far in excess of the inlet port and valve friction in the practical case and has to be tolerated to get efficient carburetion.

Leaving the question of fluid friction losses and passing to those more purely mechanical, these may be divided as follows:

(1) Losses due to driving auxiliaries, such as the fan, the water-pump, the oil-pump and the electrical equipment
(2) Losses due to bearing friction of the crankshaft, the camshaft, the valves, the gears, etc.
(3) Piston friction

The losses due to driving the water and oil-pumps and electrical equipment are neglible in most cases. The loss

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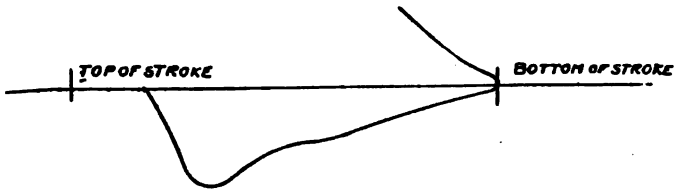

FIG. 4—LATE OPENING AND CLOSING INLET-VALVE DIAGRAM

due to driving the fan, particularly at high speeds, is however considerable, easily amounting to from 2 to 3 hp. at 2500 r.p.m. It is noteworthy that the vast majority of designers employ gears to drive the water-pumps which are often larger than those in the transmission, but are quite content to drive the fan by a belt, in spite of the fact that the fan absorbs about forty times the power required to drive the pump.

It has been known for many years that the friction of a well-designed journal bearing is exceedingly small, but it seems to have taken a long time to make the logical deduction that if the journal friction in a gasoline engine is small and the total friction absorbs some 10 per cent of the indicated-horsepower, a large proportion of this must be charged to friction between the piston and the cylinder walls. It has taken still longer to seriously attack this problem of reducing piston friction.

In gasoline engines with cast-iron trunk pistons, the piston friction is about 8 lb. per sq. in. of piston area at a piston speed of 2000 ft. per min. The magnitude of this quantity depends upon the piston thrust and rubbing velocity, the former item being very largely a function of the inertia pressure. Reduction of piston mass is obviously the first step in reducing piston friction. The advantages of the aluminum piston in this respect are

FIG. 5—EARLIER OPENING INLET-VALVE DIAGRAM

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apparent. It is not generally appreciated that the prime virtue of light reciprocating parts is the improvement of mechanical efficiency caused thereby, and that, apart from this, the net energy absorbed in reciprocating a piston is the same for heavy pistons as light, being nil.

The next point of importance is the consideration of the action between the rubbing surfaces of the piston and the cylinder wall. In the case of a trunk piston of normal design it is easily seen that the area of the oil film between these surfaces is equal to the wall area of the piston, and that as only one side of the piston is functioning at a time there is roughly four times more oil film being acted upon than is required for taking the piston thrust, which probably does not extend to more than one-quarter of the piston circumference. This unnecessary surface in contact is naturally prejudicial to mechanical efficiency. For this reason many pistons are relieved for part of their length by reducing the diameter about the piston-pin and are also drilled to reduce the surface in contact. The advantages obtained are real and distinctly shown on the test bench. Unfortunately, it has been found difficult to combine mechanical strength with lightness in these pistons and many failures have resulted from such attempts to side-track the defects of the piston of standard design. Further, the disposition of the bearing surface in pistons so relieved is not correct. There is still a 50 per cent excess of unnecessary surface, allowing for the fact that bearing surfaces have to be provided on each side of the piston, although only one side functions at a time. The rigidity of the piston-pin bosses is also seriously reduced unless the piston walls are unduly heavy. The orthodox trunk piston has been regarded by designers in much the same way as the flatness of the earth was regarded by the world in general before the voyage of the first American immigrant. It has simply been accepted without question. The success attending the various departures from orthodox construction is a very useful object lesson that no established construction is beyond improvement.

One of the earliest of these departures is the Zephyr piston shown in Fig. 6. This type of piston has been very successful in aeronautic and racing engines, some of the first specimens being used by me on racing cars in 1912. In addition to the reduced bearing surface and adequate piston-pin boss support, it will be noticed that the design of the piston crown is well adapted to dissi-

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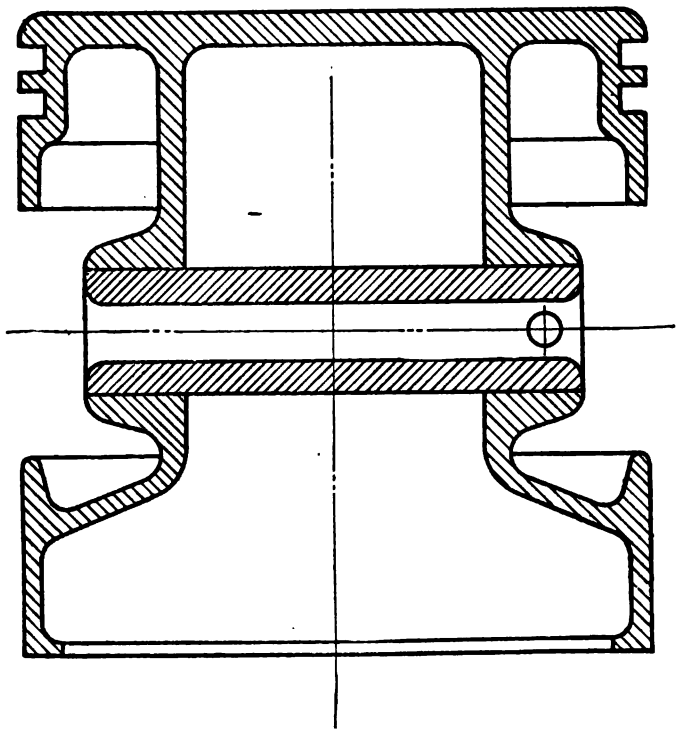

FIG. 6—ZEPHYR PISTON

pating heat. A still further development toward a rational solution of the piston problem is that of the Ricardo slipper piston. This is shown in Figs. 7 and 8. It will be seen that there are a considerable number of interesting points in this design, which can be tabulated as follows:

(1) The direct transmission of piston thrust to the slippers
(2) The proportioning of the slippers to the loads they carry, the compression slipper being reduced in area compared with that receiving the explosion thrust
(3) The slippers extend the whole working length of the piston and only laterally to the degree required
(4) Rigid support of the piston-pin bosses
(5) The ability to use a floating piston-pin
(6) Inherent lightness

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The improvement in power and reduction of gasoline consumption consequent upon the improved mechanical efficiency obtained with this type of piston varies from 5 to 10 per cent at full load and is highest at high speeds. When it is remembered that an automobile engine is only developing about 25 per cent of its maximum power during a large percentage of running, and that under these conditions the inertia force and speed elements of piston friction are fully manifested, it will be seen that the effective increase in mechanical efficiency at low loads and high speeds may be very considerable.

For example, about 10 hp. is required to propel a car weighing 3000 lb. at a speed of 30 m.p.h., with a gear ratio of 5.01; this corresponds to an engine speed of about 1550 r.p.m. at which speed an engine of say 200 cu. in. capacity is easily capable of developing some 36 hp. The load factor, according to the conditions stated, is, therefore, only about 28 per cent. The well-known

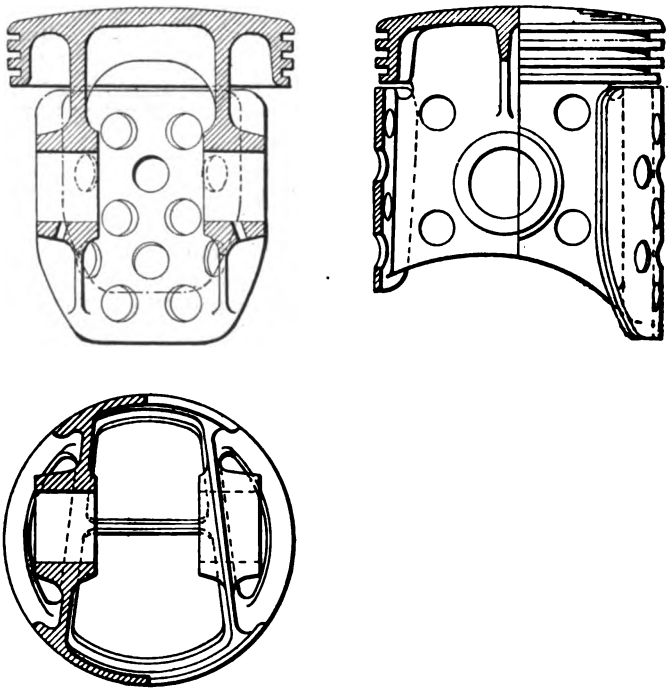

FIG. 7—RICARDO SLIPPER PISTON

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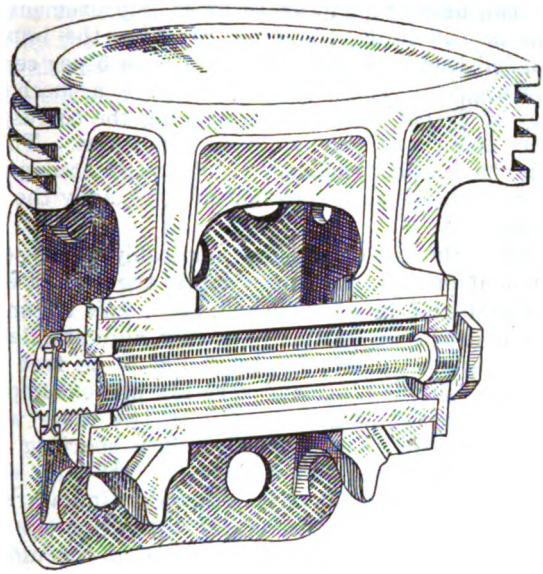

FIG. 8—RICARDO SLIPPER PISTON

law of friction of machines, that friction is independent of the load, is as applicable to gasoline engines running at constant speed as it is to the hand crane or pulley blocks of our school laboratories, especially as in the case under discussion the bulk of the loading is due to inertia effects which are constant by hypothesis.

A very fair upper limit for the mechanical efficiency of a 200-cu. in. engine with cast-iron pistons running at 1500 r.p.m. is 87 per cent. The corresponding figure with slipper-type pistons may easily be 92 per cent. The friction-horsepower for cast-iron pistons is, therefore, $\frac{36}{87} - 36 = 5.2$ hp., and for the slipper pistons $\frac{36}{92} - 36 = 3.2$ hp.

As this friction loss is virtually independent of the load, it will be the same when the engine is delivering the 10 hp. at 1500 r.p.m. as when delivering the maximum horsepower of 36 at this speed. The mechanical efficiency with cast-iron pistons, the engine delivering 10 hp., will, therefore, be 66 per cent, while with the slipper piston the corresponding mechanical efficiency will be 76 per cent, an improvement of over 15 per cent at 28 per cent

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of full load, arising from an assumed improvement of 5 per cent at full load. In actual practice, the improvement at full load is usually far more than 5 per cent, as few engines with cast-iron pistons have a mechanical efficiency of 87 per cent, thus enhancing the corresponding item under ordinary running conditions. The increase in mechanical efficiency is obviously accompanied by a decrease in gasoline consumption of exactly the same percentage.

In brief, this piston satisfies admirably the essential conditions of inherent lightness due to the correct disposition of material, in itself no small economic advantage, together with the realization of a very high standard of mechanical efficiency. It is also found to be free from the defect of oil-pumping, and very low oil consumptions have been obtained in actual use. In two cases within my knowledge the oil consumption of a sporting four-cylinder car with an 80-mm. bore by 180-mm. stroke engine was 4000 to 5000 miles per gal. Similar results have been obtained by its use on truck engines, one large omnibus company recording a decrease in oil consumption of 80 per cent as compared with results previously obtained when cast-iron pistons were used.

Still greater improvements in mechanical efficiency, thermal efficiency and oil consumption have accompanied the use of the Ricardo crosshead-type piston illustrated in Fig. 9. It will be seen that this piston resolves itself into two parts, one, the crown carrying the piston-rings and performing the essential function of preventing gas leakage; the other, the crosshead which takes the connecting-rod thrust. As the crosshead part is working in a guide that is kept cool by the flow past it of the air on its way to the carbureter, and is also ideally lubricated, the working clearance can be reduced to very fine limits so that the piston is absolutely silent. It further insulates the crankcase from the heat radiated from the piston, thus keeping the lubricating oil cool. The supply of oil to the cylinder walls can be precisely regulated and is exceedingly small in quantity, as the top of the piston does not perform any thrust-resisting functions. Further, the crankcase can be filled to the level of the crankshaft, without increasing the amount passing to the cylinder walls. The net result is a very low oil consumption of 0.01 pint per b.hp.-hr. in a 200-hp. engine at full load. There is also an almost complete absence of carbonization. The official report of a British Government department

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on an engine with this type of piston stated that at the end of a 400-hr. run the carbon could be rubbed off the piston by the fingers.

It is also a most interesting and important characteristic of engines with this type of piston that while at

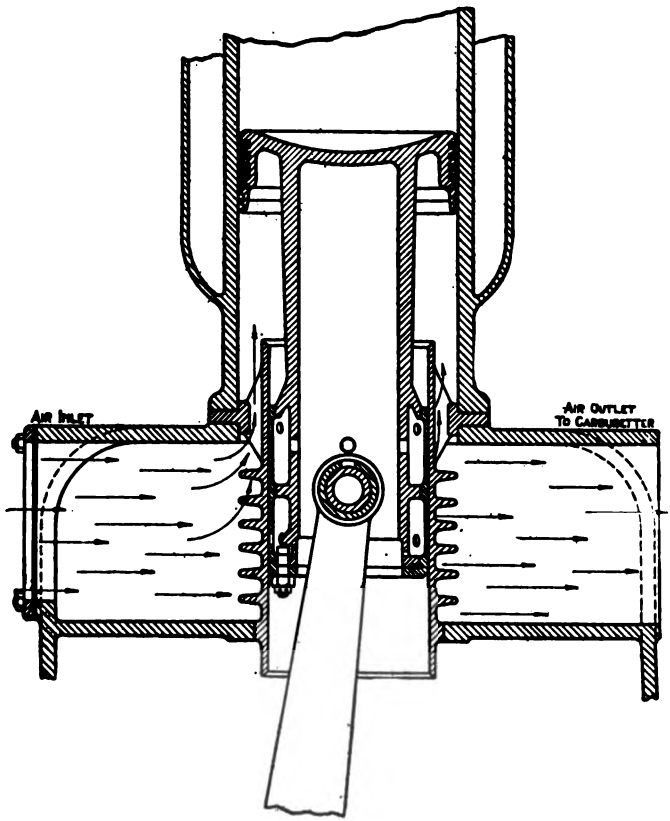

FIG. 9—RICARDO CROSSHEAD-TYPE PISTON

full load the temperature of the air in the region of the crosshead guide is about 70 deg. fahr. above atmospheric temperature, falling to that point before entering the cylinders, at light load the respective temperatures are about 90 and 30 deg. fahr. above atmospheric temperature, thus giving the ideal conditions for prevention of gasoline condensation at low loads and speeds, and when

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idling. The use of heated manifolds, hot-spots, etc., is thus rendered unnecessary.

Fig. 10 shows a tank engine fitted with these pistons. In this position the engine was required to run light for 30 min. and then to open up immediately without smoking.

In the foregoing remarks on mechanical efficiency adequate lubrication has been assumed. The relative merits of the various systems in use do not seem to have changed much and it is impossible to say that any particular one is greatly superior to the others. The system that is adopted seems to be largely a matter of taste, which indicates the verification by experience of the doctrine that

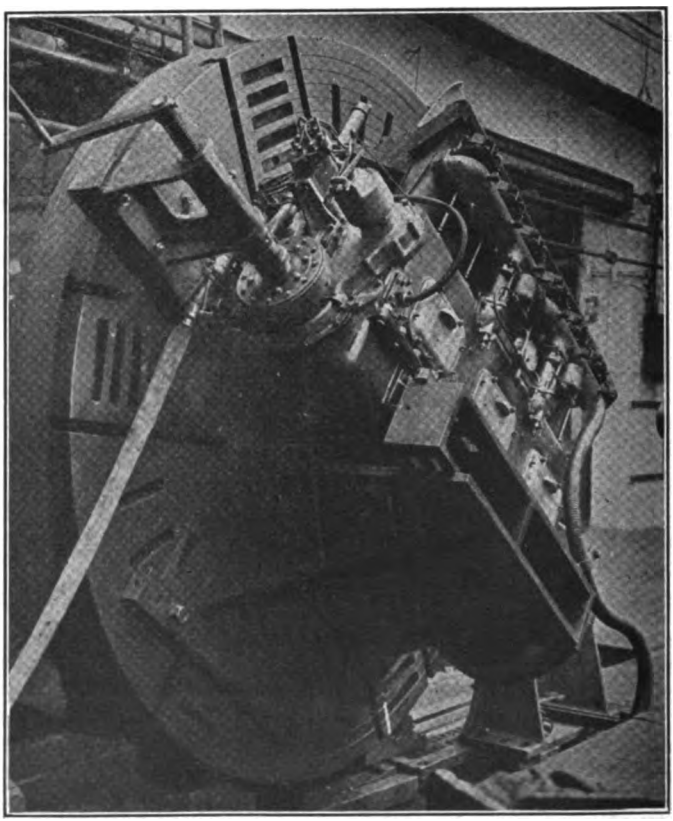

FIG. 10—TANK ENGINE FITTED WITH CROSSHEAD-TYPE PISTONS

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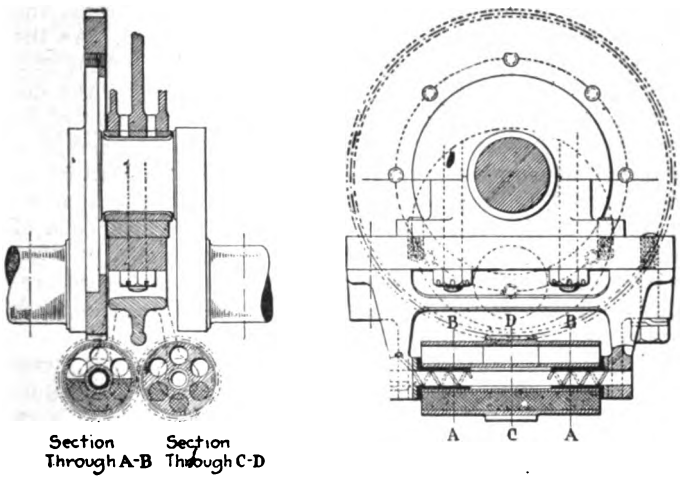

FIG. 11—LANCHESTER ANTI-VIBRATOR

a correctly designed bearing will lubricate itself if oil is led to it.

Under no circumstances is it likely, in gasoline engines, that a bearing can be oil-borne by the pressure in the oiling system. On the other hand, the advantage of forced lubrication in cooling heavily-loaded bearings by sheer volume of oil pumped is not to be lightly set aside.

IMPROVEMENTS IN ENGINE BALANCING

This aspect of engine design would more properly be termed improvement in means for reducing engine vibration, since vibration is by no means eliminated when complete balance is obtained, a fact well known to most designers of six-cylinder and even twelve-cylinder engines.

In respect to engine balance *per se*, the position to date is that engines with two, four, six, eight or twelve cylinders, are or can be completely balanced in respect to primary and secondary unbalanced forces and couples. The six and twelve-cylinder engines are of course inherently balanced; the four and eight-cylinder need the application of a device for neutralizing the secondary unbalanced forces. Fig. 11 shows the Lanchester anti-vibrator, and Fig. 12 the Ricardo secondary balancing device, each if which is effective. The principle of the Lanchester device is that of two reverse-rotating bob-weights that apply equal and opposite forces to the secondary inertia

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forces set up by pistons at the end of each stroke, the bob-weights rotating at twice the engine speed. As the energy content of the bob-weight system is constant at a constant speed, the only force required to drive the device is that arising from the friction of the bob-weight spindles, so that the driving mechanism is merely a motion transmitter. When the engine is accelerated or decelerated, tooth pressures of material magnitude arise, but can be dealt with easily. The peripheral speeds of the gears is 90 ft. per sec. at an engine speed of 3000 r.p.m., approximately the same as with many turbine reduction-gears in daily use, where, in addition, the tooth pressures are exceedingly high.

The Ricardo device is based upon the principle of introducing reciprocating masses driven by linkages, producing the same angular effects in respect to inertia with these masses as the connecting-rod crank system produces with the pistons. It is exceedingly ingenious. The conditions under which the pin-joints in the linkage systems work are no worse than those of the piston-pin, and although the device appears a little complicated, it is simple in detail and works well. It has not, however, the advantage of ready application to existing designs possessed by the Lanchester anti-vibrator. I have corresponded with many people on the subject of secondary balancing and have found a general vagueness of thought thereon, many confusing secondary balancing with crankshaft torsional damping and still more stating that they had attained the same ends by crankshaft counterbalance-weights. Whatever effect counterbalancing may have in reducing bearing loads, it certainly does not, *per se*, affect the balancing problem one way or the other. The only virtue of crankshaft counterbalancing, the addition of balance weights to the crank webs so that each individual crank and attached rotating masses may be balanced, is that wear on the middle main-bearing of the crankcase can thus be practically eliminated, and the crankcase itself reduced in weight very considerably.

The whipping tendency or "skipping-rope action" of an unbalanced crankshaft, particularly in a six-cylinder engine, sets up very heavy bearing loads and crankcase stresses, so that counterbalancing may be very desirable in engines with center crankshaft bearings. The elimination of the center bearing, another accepted fetish, dodges the bearing loading problem very well, and will doubtless be more widely adopted than at present. Further, the

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use of counterbalance-weights should be accompanied by an increase in crankshaft diameter, owing to the torsional mass effects of the balance-weights which may easily exemplify the adage that the cure is often worse than the disease.

Apart from the question of structural rigidity, recipro-

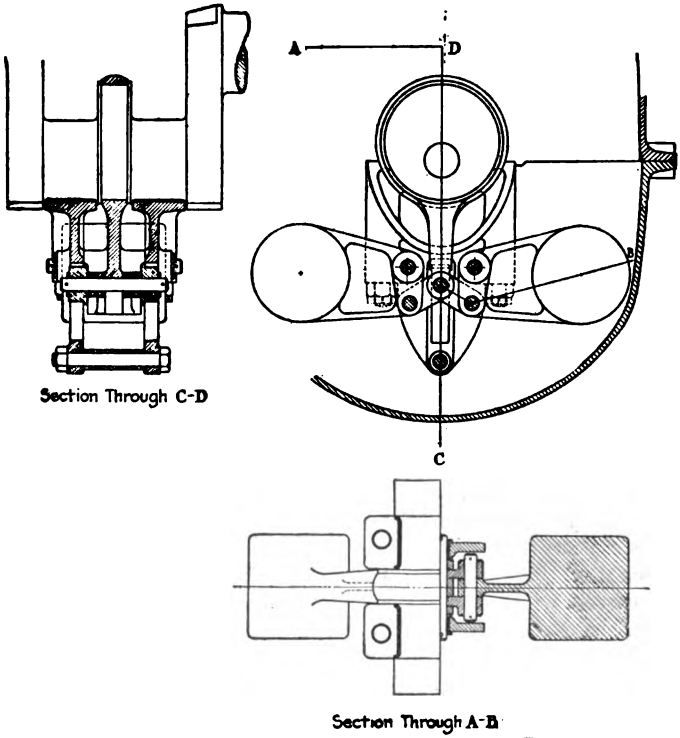

FIG. 12—RICARDO SECONDARY BALANCING DEVICE

cating mass effects present no serious problems nowadays, irrespective of number of cylinders and crank disposition. The question of vibration can therefore be studied in the light of how far it is necessary or desirable to increase the number of cylinders, in order to satisfy the legitimate demand for smoothness and flexibility of running. From this viewpoint the chief factors are

(1) Uniformity of torque
(2) Torque reaction
(3) Inertia torque variations

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Uniformity of torque is a matter of number of cylinders on the one hand and flywheel weight on the other. By flywheel weight here is included the whole mass of the car in the automobile application of gasoline engines. In other applications the choice between increasing the number of cylinders on the one hand or the weight of the flywheel on the other would be a matter for purely individual taste, if the problem had no other aspect. In either instance, sufficient torque uniformity can be obtained to satisfy the most exigent case.

The question of torque reaction is not disposed of so easily. It is in respect to the reactive effects upon the crankcase supports, caused by the fluid pressure in the cylinders, that 75 per cent of the argument lies in the choice of the desirable number of cylinders, particularly for automobile use. In a discussion of this kind the point that the purchaser wants a six, an eight or perchance a twelve-cylinder car and therefore must be so supplied is quite irrelevant except insofar as it calls for an analysis of the situation in general. Whatever the reason for the public taste with regard to multi-cylinder engines, whether it be actuated by advertising or genuine need, the outstanding fact is that the multi-cylinder engine has a large following, and therefore gives the purchaser something which appeals to his sense of comfort and fitness.

It is the business of engineers to translate the often inarticulate but nevertheless real desires of the user into mechanical terms, and to consider how design can be improved without demanding any sacrifice from the user regarding the standard of performance with which he is satisfied. Whether the result, in gasoline-engine design, is an engine with fifty cylinders or none at all, is of little importance. The ultimate test of sales indicates as frequently as not that, given equal performance, a new article cleverly advertised will scare the sales departments of competitors into demanding novelty even at the expense of proved worth and reliability. And of this it would be difficult to find a better example than that displayed in the history of the eight-cylinder car in America and the six-cylinder car in Europe.

With these remarks I would submit that torque reaction is one of the chief problems before engine designers today. The combination of low-gear ratios and large multi-cylinder engines, which have occurred simultaneously, entirely masks the problem from the viewpoint of performance. The "feeling" of a four-cylinder light

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low-geared car in respect to acceleration and flexibility is practically indistinguishable from that of an eight-cylinder car of the same gear ratio and capacity per cylinder but twice the weight. In a previous contribution this aspect of the case has been dealt with in some detail, and all that would seem pertinent here is to urge again that automobile engine design is but one phase of the much larger problem of car design. If in reference to acceleration, slow running, capacity for high-gear work, and, last but by no means least, absence of apparent torque reaction, it can be shown to be reasonable that the attainment of an accepted standard is primarily a function of car weight, the number of cylinders which will fill the conditions reduces itself to a matter of simple arithmetic.

It is quite conceivable that the four and the eight-cylinder engines may win out, each in their respective spheres. They are natural relations and between them they can certainly fill any existing demand. Unfortunately the eight-cylinder engine as now designed is very wide and precludes in some cases an artistic hood and radiator design. But this is by no means inherent in the type, as a later section of the paper will indicate. Briefly, the case for appearance in relation to the eight-cylinder engine rests upon the short-stroke engine with short connecting-rods and secondary balancing, and an "eight" designed from this viewpoint should present many attractive features.

In the list of the factors contributing to vibration disturbance, mention was made of the torque variations due to piston inertia. This subject is but little appreciated and a few words may be of interest. This torque variation arises from the fact that the pistons are brought to rest twice per revolution, thus causing alternating tension and compression forces in the connecting-rod. The horizontal component of these forces evidently tends to rotate the crankcase about the crankshaft axis and causes a variable torque reaction upon the crankcase supports. Under certain conditions these reactions are neutralized by the fluid pressure in the cylinder. A little thought will show that if at the latter part of the compression stroke the connecting-rod is in tension due to piston inertia, this tension can be neutralized, or in fact altered to compression, by the fluid pressure upon the piston due to compression. Under these circumstances the torque reaction due to fluid and inertia

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pressure will be zero. There is clearly a field of engine speed and compression pressure in which the compression will largely neutralize the torque variation due to inertia.

As the compression pressure may be considered constant with an increase of speed and the inertia effects vary as the square of the speed, it is obvious that the inertia effects will start by being less than the compression effects and gradually eclipse and finally exceed these. This inertia torque variation is often unpleasantly manifested when the throttle is suddenly closed at high speeds, and the cushioning effect of the fluid pressure removed. Many engines then behave as if a bag of nails had been introduced into the crankcase, and at least one patent has been filed relating to carbureters in which the supply of gasoline but not air is cut off when the throttle is suddenly closed. The fundamental remedy is to neutralize the inertia effects at the source.

Fuel and Carburetion

The problems arising from the deterioration in the quality of gasoline and the economic necessity of using low-grade fuels in gasoline engines, have been the subject of very extended study in America and been discussed far more authoritatively than is possible here. Fuel questions are indigenous to America, and find their natural solution among American engineers. There are, however, one or two points relating to the trend of engine design to which reference may be made.

The chief troubles arising from the use of present-day gasoline, the word low-grade being now superfluous, are

(1) Detonation or pinking
(2) Prevention of gasoline deposition in the crankcase

Detonation may be considered as an instantaneous increase in pressure as distinguished from an explosion in which the time factor is marked and measurable. In a mixture of gasoline and air, it apparently depends upon the pressure and chemical constitution of the gasoline at the instant of ignition rather than upon the temperature. Fuels containing a proportion of the aromatic series or of benzol, are far less susceptible to detonation than those not so constituted. Detonation is also less likely to arise if the mixture is in a state of violent turbulence so that ignition can spread rapidly through the charge. If this is not the case, local ignition apparently sets up a compression wave that spreads more rapidly than the

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ignition so that when the ignition takes place in parts of the charge remote from the firing point, the charge is very highly compressed and therefore detonates.

The use of benzol in even small proportions of 10 to 20 per cent will allow much higher compressions to be used than are possible without such addition. The admixture of cooled exhaust-gas has the same effect and has been used for many years on producer-gas engines where very high compressions are common. The application of this idea to gasoline engines generally is now being worked out and will doubtless become common. The difficulties are purely of detail application and in the automobile engine largely arise through the necessity for part-throttle working. I have applied cooled exhaust-gas to a badly carbonized engine that simply would not run at full throttle with the result that full throttle could be used, the torque obtained being within 1 per cent of that given by the same engine when clean.

Many interesting data on this subject of detonation have been contributed by Mr. Kettering. His researches in this connection are eminently worthy of detail study. The curves he has obtained show clearly that detonation occurs well down on the firing stroke, which supports the view that it occurs through delayed local ignition of a highly compressed part of the charge.

The subject of gasoline deposition in the crankcase is one of more practical importance than a problem involving physical speculation. It has been known for many years that the lubricating oil in the crankcase gradually absorbs gasoline, and retains such fractions as are not volatilized at the temperature of the lubricating oil during use. With prewar gasoline, the maximum absorption was about 4 per cent. Nowadays, when fully one-third of standard gasoline does not vaporize under a temperature of 140 deg. cent. (284 deg. fahr.), deposition is much more serious. It can be dealt with once and for all by the use of the crosshead piston described above. On the other hand, this cannot be applied without radical alteration in design. The use of high-temperature induction pipes is therefore indicated to vaporize the gasoline-air mixture as much as possible before it enters the cylinders. The standard method of exhaust jacketing the induction manifold seems defective in that the heat supply is least at part throttle, when it is most required, and greatest at full throttle, when it is least required. The correct way seems to be to reverse this state of

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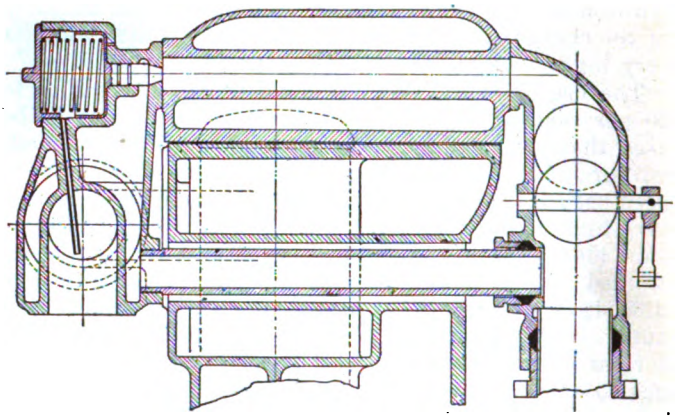

FIG. 13—EXHAUST-HEAT DEVICE IN WHICH THE HEAT SUPPLY IS CUT OFF AT FULL THROTTLE

affairs. A device which would satisfactorily and automatically pass the greater part of the exhaust-gases through the manifold jacket at low throttle and only a small portion at full throttle appears to be desirable.

Such a device is illustrated in Fig. 13. It depends for its action upon the vacuum in the inlet manifold, which is more or less in accordance with the necessity for external heat supply. The spring-loaded piston is in communication on one side with the induction pipe and at the other forms a valve controlling the amount of exhaust-gas which can pass into the inlet-manifold jacket. At a small throttle opening, or a high vacuum in the induction pipe, the maximum amount of exhaust-gas is passed into the manifold jacket while at full throttle, or a low vacuum, the supply of exhaust-gas is cut off, thus avoiding unnecessary preheating of the mixture.

It seems probable that the maximum deposition of gasoline in the crankcase occurs when the engine is started. At this time the cylinder walls are covered with cold oil which is quickly scraped off by the rings and not replaced with further lubricant until the engine becomes warm. Further, the gasoline which is used during the first few minutes after starting is that which is left in the float-chamber after the previous run, from which the lighter fractions have already in all probability disappeared. The same condition holds for vacuum tanks, where the surface of the gasoline is exposed to the atmosphere. It was the custom among the

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drivers in the Mechanical Transport Department in France to drain the carbureter float-chamber before starting up and, as engine starters were not in common use, the practice may be accepted as one that was really necessary. Since the preheating of induction-pipe manifolds before starting is very advantageous, the draining of the float-chamber, if arranged for, as it can be, so that no troublesome operations are involved, will minimize the serious effects of gasoline deposition.

In respect to carburetion generally, the difficulty is primarily in securing proper distribution. It has been realized that it is much easier to produce a spray of gasoline and air in requisite proportions at all loads and speeds, than it is to insure that this spray is distributed equally in correct quantity and quality to the cylinders.

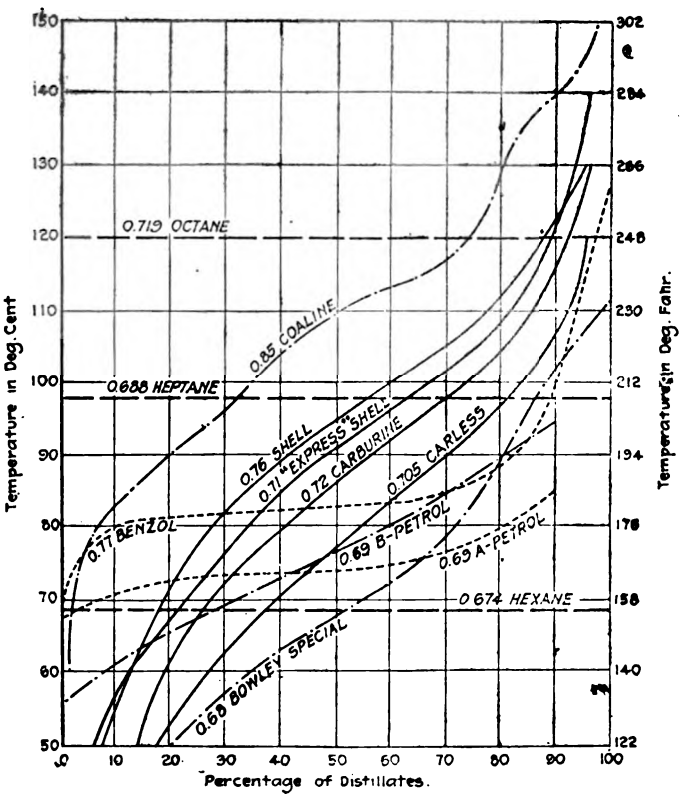

FIG. 14—FRACTIONAL DISTILLATION CURVES OF FUELS AVAILABLE IN 1908

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There does not seem to have been much radical improvement in induction-manifold design, although there is less variation in this respect in engines than existed a few years ago. The principal detail improvement is possibly the reducing of the size of the manifold so that a high gas velocity is attained through it. There is a real need for an inlet manifold the area of which will adjust itself to the requirements of the moment, being large at full load and small at light load. A flexible lining of the manifold, with a space between it and the manifold open to the atmosphere, would seem to possess the property of collapsing at light loads when the vacuum in the manifold is high and of expanding at full load when the vacuum is low, thus producing an area proportional to the load. On the whole the situation is probably accurately summed up in the words of Mr. Howard Marmon to the author, "No deposition, no distribution problem."

Fig. 14 shows the fractional distillation curves obtained by G. H. Baillie, published in 1908 in a paper read before the Royal Automobile Club. These are of interest as recording the properties of gasoline of a decade ago, and indicate strikingly how the carburetion problem has changed in respect to the fuel itself.

The "war spirit" used in England during the last three years, when fractionally distilled, only evaporated some 70 per cent of its volume under 140 deg. cent. (284 deg. fahr.), while the 0.76 shell in Baillie's experiments was completely evaporated at this temperature.

Materials

It would be neglecting the subject of the trend of engine design not to deal somewhat fully with materials, and the principles underlying the choice of material for various purposes. The literature and practice of the past five years indicate that the physical properties of materials are considered far more intelligently than ever before and that design is based upon some knowledge of the real and intrinsic merits of the materials in use. The term "a stiff steel" is seldom heard now that it is more generally appreciated that all steels possess approximately the same stiffness. Further, the nature of fractures and the causes thereof have received much attention by metallurgists, or rather the metallurgists have come out of their lairs, removed their all-seeing eyes from their microscopes and condescended to explain

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to the engineers in fairly plain English the nature of the metals they use and the mechanical properties these metals possess. Even at this date papers are being read by eminent metallurgists speculating upon what happens when a piece of steel is broken.

The principal materials at the disposal of the engineer are as follows:

Steels, alloy and carbon, both high-tensile and case-hardening
Cast iron
Aluminum, forged and cast
Bronze, phosphor and manganese alloys
Bearing metals containing lead, tin, copper and antimony

The choice of material for any specific part calls for considerable judgment to obtain the best results. It is perfectly easy to specify a high-tensile alloy steel for a crankshaft on the grounds that this is accepted high-class practice, although for automobile engine purposes, even of the highest class, this may be sheer waste of money. The average stress in a crankshaft of the solid type is very low, and does not justify high-tensile alloy steel except from one point of view. This is the local increase of stress in small fillets explained previously. As the intensity of stress in a fillet varies inversely as a high power of the radius, it would seem far more rational to eliminate these high local stresses by increasing the radius of the fillets, than to use a considerable weight of high-tensile material all through with attendant expense and difficulty of working. In all cases, subject to the above reservation, the dimensions of a crank are those required for stiffness rather than strength, and are largely in excess of stress requirements. The actual deflection under a given load of two crankshafts of identical design is strictly in proportion to the relative moduli of elasticity of the materials of which they are composed. These do not vary more than 2 or 3 per cent in any of the steels in common use, the higher values for stiffness being frequently obtained with the lower-tensile steels. For the above reasons there is little advantage in the use of expensive alloy steels for cranks unless their properties are essential to overcome bad design or are made necessary by the need for a reduction in section without sacrificing stiffness, as in bored-out aeronautic engine crankshafts. In fact, the use of carbon steel properly heat-treated is very much overlooked in engine construction generally.

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The advantage of alloy steel has largely disappeared with increasing knowledge of heat-treatment and stress distribution.

In respect to physical tests, the old-fashioned tensile test probably gives the best indication of the relative qualities of steels in general, in spite of the fashion to regard shock and fatigue tests as decisive. It is worthy of remark that the high-tensile steels invariably give much lower impact-test figures than low-carbon low-tensile steels. The real point is that impact and fatigue tests only convey information as to the capacity of the material to resist fracture, when stressed outside its elastic range. If such stress condition occur, fracture is bound to occur sooner or later, and if such is the case, the precise amount of energy absorbed during fracture does not possess much interest. It seems more important to have accurate information upon the true limit of proportionality of stress and strain, and in general much more information of the behavior of steel inside the so-called elastic range.

My practice in specifying and using steel has been to insist upon having the analysis of the steel within reasonable limits and to be sure, from micrographic examination, that the steel possesses the desired structure for the particular purpose intended. With these two points assured, physical properties will usually take care of themselves. An illustrative example of the futility of trying to combine high-tensile and high-elongation properties arose in England during the war in connection with aeronautic engine crankshafts, many perfectly sound cranks being rejected which would have been passed in the light of analysis and micrographic examination.

Of cast iron, little need be said except that machining and wearing properties are usually inconsistent with each other. It seems a pity to use soft cast iron which wears rapidly at the high piston-speeds in common use, for the sake of a slight saving in machining time.

Aluminum has been greatly improved in the last few years. It is beginning to respond and yield to the ingenuity and long-continued ministrations of the metallurgists. The ideal of combining its lightness with the properties of steel is still far off, but very much of its frailty of character has been removed, without affecting its physical lightness. In the cast state, it is possible to obtain an ultimate tensile stress of 27,000 lb., with an elastic limit of 10,000 lb. and an elongation of 5 to 6

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per cent. The elastic limit is sufficiently well marked to indicate that it can be raised by overstrain similarly to that of steel. A new material is thus presented to the engineer.

The peculiar virtue of aluminum for castings is that the weight is not limited by foundry considerations, as in the case of cast iron and cast steel. This renders possible a scientific disposition of material, which is exceedingly important in getting the maximum effectiveness out of a given volume of metal.

It is safe to say that 90 per cent of engine castings could be made with perfect safety from the same drawings, whether in aluminum or other cast metal, thus reducing the weight by about 60 per cent. By taking advantage of the freedom of design conferred by the strength qualities and light sections permissible in aluminum, this reduction in weight for a given casting can be considerably improved. In the case of the cylinder, problems of wearing surface arise apart from foundry considerations, but the use of the aluminum cylinder with inserted liners has already proved so successful in aeronautic and automobile practice, as to justify serious attention from the point of view of present and future design. Nor is the high cost of aluminum so serious a bar to its wide adoption as would appear. As against malleable iron, it is about three times more expensive. As it is about one third the weight, castings from the same patterns would cost about the same.

Further, the great facility with which aluminum can be machined and the high costs borne by machine-shop labor are factors in cost of production which often completely offset the higher cost in raw material form. As a practical example arising from aluminum shortage during the war, I was ordered by a British Government department to make certain crankcases and gearboxes of cast iron. A careful investigation showed that there would be no saving in the cost of production and that the necessary extra machine-tool equipment would have entailed a capital expenditure with attendant labor and overhead charges sufficient to make the whole scheme impracticable. The case for aluminum as a structural material rests therefore upon the ease with which it can be worked, the absence of foundry limitations from the point of view of weight in castings such as crankcases and cylinders and the fact that the strength of cast aluminum is now far in excess of what it was a few years ago.

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The relative weights per unit tensile strength are as follows, the figures being based upon the ultimate tensile strength in each case:

	Weight per Cubic Foot, lb.	Tensile Strength, lb. per sq. in.	Tensile Strength ÷ Weight per Cubic Foot
Aluminum	170	27,000	159
Gun Metal	500	31,000	62
Malleable Iron	480	40,000	83
Cast Steel	480	60,000	125

As a material for flywheels, aluminum would seem unsuitable, as indeed it is for certain classes of engines, but even for this purpose its inherent strength for a given weight calls for attention. The usefulness of a material for flywheels is determined by the peripheral speed at which it can be run without bursting from centrifugal effects. From this point of view a material is required which has a high ratio of strength to weight per cubic inch. Comparing forged steel with an ultimate strength of 80,000 lb. per sq. in. to cast aluminum with an ultimate strength of 27,000 lb. per sq. in., we obtain the following:

$$\text{Forged Steel} \frac{80000}{0.28} = 2.88$$

$$\text{Cast Aluminum} \frac{27000}{0.1} = 2.7$$

showing that for cases in which space considerations do not set a limit, as in automobile engines, aluminum is far from being a negligible material for flywheels. It is probable that for moderate-sized flywheels, such as are required on direct-driven alternating-current generators, the use of aluminum would be economical in comparison with forged steel. The use of aluminum is also indicated for turbine disks and other cases in which the limit of speed depends upon inherent strength to resist the forces set up by inertia and centrifugal forces. Although these examples are not directly connected with automotive engine design, they are suggestive by reason of the fact that engine sizes and speeds are now rapidly approaching the state in which stresses due to inertia form the basis of engine design.

It is also of interest to compare similarly the strength of forged aluminum with that of various steels, taking for examples a mild carbon steel, a high-tensile carbon steel and a high-tensile chrome steel.

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	Weight per Cubic Foot, lb.	Tensile Strength, lb. per sq. in.	Tensile Strength ÷ Weight per Cubic Foot
Aluminum (forged)	170	60,000	350
Mild Steel	480	60,000	124
High-tensile Steel	480	100,000	208
Nickel-chrome Steel	480	135,000	280

The advantages of aluminum in replacing steel forgings are best exemplified by the case of the connecting-rod. In the case of a steel connecting-rod, minimum weight can be obtained only by delicate machining operations, which are further complicated by the necessity for avoiding sharp radii and fillets to obtain good stress distribution. In other words, the normal steel connecting-rod is about twice as heavy as it would need to be if the material could be properly utilized. With forged aluminum difficulties in respect to machining operations and stress distribution naturally disappear, and the designer has so much "lightness in hand," so to speak, that local high stresses, as for example those in the middle of the big-end cap parallel to the crank axis, can be dealt with liberally without appreciable increase in weight.

In general, compared with steel, the case for forged aluminum rests upon the fact that the strength of members subject to bending or torsion depends upon the ultimate stress and the cube of a linear dimension, while the weight is a function of the square of a linear dimension. Thus, comparing two square beams subjected to bending, one being 1 in. square and the other 1.41 in. square, the second is twice as heavy, nearly three times as strong and four times as stiff as the first, thus showing the overwhelming effect of dimensions *per se* and the relative unimportance of high tensile strength in members where ample space is available, as in the case of the connecting-rod mentioned above.

Lightness of Construction

The development of the aeronautic engine has focused the attention of designers and the public upon the light engine. In the case of the aeronautic engine, lightness is obtained mainly through machining out low-stressed portions of the various members concerned and because the large size of these engines renders them less susceptible to the limitations imposed upon lightness by foundry and forge considerations. It is not necessary to use twice as much material as is required to make a part which would work perfectly, providing it could be

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got in place without its being broken by dropping upon the shop floor. In the case of gasoline engines generally, such methods of obtaining lightness are either precluded or prohibitive in cost.

Apart, however, from the use of material of high specific strength and low density which side-tracks foundry and forge difficulties, there remains the consideration in the light of recent knowledge of the all-important question of engine proportions from the point of view of least weight. There has been during recent years a decided tendency toward the long-stroke engine in which the stroke is more than one and one-third times the bore. This has arisen probably through a combination of taxation by bore in England and the great success of the long-stroke racing engine. The taxation aspect of the case is not of importance in America, so that it may be of interest to scrutinize the question in some detail from the point of view of pure design. I have been for many years an advocate of the familiar 3½ by 4¾-in. engine for use on moderate power touring cars. I have also been successful to some extent in developing the touring engine of this type for racing purposes, having created world records with such an engine in 1912. In 1913, the Peugeot 3-litre racers appeared and more or less swept the board in this class. They were undoubtedly very fast and, what is more, were equipped with probably the first reliable overhead-valve high-speed racing engines ever built. Their success gave an impetus to the long-stroke movement, in Europe at any rate, and it may therefore be interesting to compare the Peugeot performance from the point of view of power with that of the 20-hp. Vauxhall 3½ by 4¾-in. touring-car racing engine with side valves which I designed and built. The speed of the Vauxhall on the half-mile track at Brooklands was 100.8 m.p.h., while that of the Peugeot 3⅛ by 5.9 in. of the same capacity with four overhead valves per cylinder was 105. The bodies were as nearly as possible equal in windage and the gear ratios about the same. The difference in speed was due, in my opinion, much more to the overhead valves and consequent better cylinder charging than to any variation in stroke-bore proportions. The difference in power, or more properly mean effective pressure, was probably not more than 10 per cent.

It is obvious that if the mean effective pressure is independent of the stroke-bore ratio, the same power

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will be developed by engines of the same cylinder capacity at the same speed. Aeronautic engine experience throws considerable light on this question, some of the latest engines being of the short-stroke type and developing mean effective pressures as high as those with longer strokes. In aeronautic engines overhead valves are universally used, so that adequate turbulence is obtained in the combustion chamber, due to the compact shape of the latter. In the case of automobile engines it is undoubtedly easier to obtain turbulence in long-stroke engines with side valves, than in short-stroke engines with side valves, but the difference is only a small percentage and there is, as already indicated, reason to believe that the combustion chamber of a side-valve engine can be modified so as to negative entirely its apparent deficiency in respect to turbulence.

If, then, the problem of stroke-bore ratio can be denuded of its power aspect, which also carries with it thermal efficiency, the ratio of stroke to bore can be settled on the basis of minimum weight and manufacturing convenience. From these points of view the short-stroke engine has everything in its favor. To begin with, the overall length of the engine is usually settled by the summation of the valve diameters, which are necessarily settled by the cylinder capacity, being the same for both long and short-stroke engines of the same capacity. The overall crankshaft length, therefore, is also settled, since the bearing lengths should be proportional to the cylinder capacity, which is independent of the stroke-bore ratio. On the other hand, the larger throw of the crank of the long-stroke engine increases the weight directly, while its inherent extra "crankiness" calls for larger dimensions, if equal stiffness and freedom from vibration are to be assured.

Following the extra crank-throw is the extended section of the crankcase, necessitating extra ribbing and metal for strength and stiffness, extra height on the cylinders due to the longer stroke and longer connecting-rods, if the ratio of crank length to connecting-rod length is to be the same as in the short-stroke engine. The length of valves and camshaft center distance from crankshaft are also increased in the long-stroke engine, the latter calling for considerably heavier timing-gear than otherwise required. The fact that it is far easier to increase the output of a given engine by boring out the cylinders than by increasing the stroke, is in itself an indication of the line of least resistance in design.

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I am confident that a restudy of the stroke-bore ratio problem will result in a reaction toward the short-stroke engine, with all its unquestioned charm of sweet running and flexibility. From the point of view of lightness, efficiency and power per weight, it is significant that the latest aeronautic practice should have broken away so completely from the long-stroke superstition by which aeronautic engine design was held in thrall only a few years ago. What is good in principle for aeronautic engines is also good practice in general so far as it can be applied. Above all, the lessons to be learned from the aeronautic engine which are of general application, is that of the proved fact that the short-stroke engine compares favorably with any other type. Because of its inherent lightness and reduction in quantity of material required, it is also economic in the fullest sense, another happy example that the best may be the cheapest.

The short-stroke engine has particular claims to attention from the designers of eight-cylinder car engines. The trouble with such engines is that they involve considerable overall width and can only just be packed into a hood which will conform with the body lines. Even then it is not possible to adopt the high hood which, with suitable treatment, can be made so charming in appearance and to harmonize so well with modern body design. The short-stroke engine permits this desirable end to be realized. It should be remembered that for a given ratio of connecting-rod to crank length, say 2¼ to 1, a 1-in. increase on the stroke means at least 1⅝ in. on the overall height; ½ in. on the crank-throw and a 1⅛-in. lengthening of the connecting-rod centers.

In the case of an eight-cylinder engine of 3¼-in. bore and 5-in. stroke, with connecting-rods two and one-third times the crank length, the pistons being 1.6 in. from piston-pin center to crown, the distance from crankshaft center to piston crown is as follows:

Crank, in.	2.5
Connecting-rod, in.	11.5
Piston-pin to Piston Crown, in.	1.6
	15.6 in. Or, say 15.5 in.

With cylinders of 3.75-in. bore and 3.75-in. stroke, or approximately the same capacity, the same connecting-rod to crank ratio and the height from piston-pin to piston crown ⅛ in., we have the distance from crankshaft center to piston crown:

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Crank, in.	1.875
Connecting-rod, in.	8.800
Piston-pin to Piston Crown, in.	1.800
	12.475 in. Or, say 12.5 in.

With the same figures as above but using secondary balancing, allowing a connecting-rod to crank ratio of 1.9, we have:

Crank, in.	1.875
Connecting-rod, in.	7.125
Piston-pin to Piston Crown, in.	1.800
	10.800 in. Or, say 10.75 in.

The approximate saving in overall width in an eight-cylinder engine, with cylinders at 90 deg., is obviously two and one-half times the saving in height given above, so that the second case would save 4¼ in. overall width over the first, and in the last case the overall width would be reduced by not less than 6¾ in. Designed upon these principles, one of the most serious objections to the eight-cylinder engines goes by the board, and it becomes possible to house it under the same well-shaped hood as now accommodates a four or six-cylinder engine.

Cleanness of design, both outside and in, is being appreciated more every day. The day is rapidly approaching when the public will demand that the automobile shall not be a means of transportation only, but susceptible of artistic treatment in just the same degree as a yacht or a house. The first law of beauty in construction of any kind is that the part shall be the one best fitted to the purpose. In this is postulated a fundamental natural economy, since it implies that excess of material or complication must be avoided.

Some day, perhaps the eight-cylinder car builders will put their heads together and work out a design that will satisfy the æsthetic tastes already inculcated by the six, and embark upon a new and interesting phase of the battle of the cylinders. And when the eight-cylinder car builders have done so and evolved a car that looks thoroughbred rather than cross-bred, it will be interesting to watch the developments of six-cylinder car builders who have been helped as much by the appearance arising from the use of six-cylinder engines as by their intrinsic merits.

THE DISCUSSION

CAPT. R. W. A. BREWER:—I have been here for three and a half years inspecting on behalf of the British Gov-

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ernment Mechanical Transport Department, seeing exactly what you were doing and what you could do, and the remarks of Mr. Pomeroy to the effect that while being conducted over many American factories he has seen the vindication of principles he has held for many years in relation to cost of production; that by sheer manufacturing skill and enterprise work of the first quality is produced; that complex parts seem to have no terror for the production department; that any rational increase in the complexity of design does not appear to be a consideration in arriving at a desired result; and that the engineer is far less limited in attaining his ends in the United States than in Europe, are fully borne out by my own experience and by that of other inspectors. The point is, that we fully appreciate the very fine quality of work that you have been able to do in mass production here in America, by American methods. On our part, we have felt that we had to act with discretion and with knowledge of our business, so that we could cooperate with you and your production departments, adjusting the limits of accuracy to suit your methods, by which you were able to produce in quantity reasonably, without condemnation of parts that were perfectly satisfactory for their intended purpose. That is the crux of the whole situation. Where you want to produce by American quantity methods real good work that is good for the purpose for which it is made, it undoubtedly can be made the best in the world.

Mr. Pomeroy's paper deals with so many vital subjects that I shall refer to only one small section, to which I am devoting my entire attention, the question of handling liquid fuel in the manifold and the carbureter. It is very interesting to note the keenness of mind of the American engineer toward the problems involved.

The intake manifold has received less attention in proportion to its deserts than any other part of the engine. It is as vital to the performance of the engine as the carbureter or the magneto, and there is science behind them. Furthermore, the carbureter and magneto depend for their correct functioning upon the intake manifold; because, however good an ignition system may be, with a bad intake manifold it cannot function properly, and both are blamed for things for which they are not responsible.

I will at this moment draw to your attention certain vital points not fully realized and dependent one upon the other in the correct design of an intake manifold. At

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the 1913 Meeting of the Society on the Great Lakes, we discussed the intake manifold in a small way. I argued that the intake pipe was an unnecessary evil and should be abolished. That pipe has disappeared in the meantime; it has taken some years to eliminate it, but it has disappeared. The point was not fully realized at the time and I gave you no indication as to what I considered the proper way to manifold an engine; but I have since done much work along these lines. The trend of design is right, although slow. For an engine to function, a dry, cool, homogeneous mixture is required, distributed to the cylinders in equal quantities.

J. G. VINCENT:—I have been engaged in research to find out what the real advantage of the I-head engine is. This experience has given me much renewed interest in the L-head engine. Considering that the automobile engine operates at a very small percentage of its total output 95 or 98 per cent of the time and investigating the question deeply with an open mind, it is found that there is not the added efficiency in the overhead-valve engine that might be expected.

I have been astonished at some of the economy figures obtained from an improved L-head engine and make the prediction that during the next few years we will see a stronger tendency to retain or return to the conventional L-head design. In my opinion we will see many detail improvements brought about in this design and, in this connection, I mention the forged aluminum connecting-rod, which has, I think, distinct possibilities. It is my belief that the tendency in design will be toward refinement of details and the development of new materials, rather than toward any radical departure to new types.

THOMAS S. KEMBLE:—Incompatibility between various requirements, such as turbulence and volumetric efficiency, as brought to light by recent progress, is not so serious as to be discouraging. We know, on the contrary, that the field for skill and ingenuity along the line of harmonizing these apparently contradictory factors grows with added knowledge. Furthermore, we have much that is of direct aid and contains few symptoms of incompatibility. Necessity for high-duty light-weight engines has resulted in a rearrangement of ideas regarding such matters as stroke-bore ratio and the use of aluminum. It has helped to bring about improved balancing arrangements and threatened old ideas of the ratio between stroke and length of connecting-rod. Reliability requirements have

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produced great improvements in ignition apparatus, valves, valve mechanism and various simple means for providing great stiffness without undue weight or expense. Allowable bearing pressures have been increased to such an extent that radical practice before the war is conservative now. At the same time bearing wear has been practically eliminated. Piston friction is being reduced and the piston-ring has been brought to a more rational basis. We have proved in practice that narrow rings come to a bearing more quickly and form as good a seal as the old-style wide rings. Their life is less only in cases where the cylinder bore has been improperly finished. Piston-ring friction decreases in proportion as the width is reduced. The only limitation in this direction consists in the fact that rings must be wide enough to avoid excessive breakage in handling.

It seems to me, in view of these and other similar facts, that we may expect in this country automobile engines capable of delivering at least 1 hp. for every 5 lb. of engine weight. No sacrifice need be made of characteristics demanded of high-class automobile engines today, and the manufacturing cost need be no greater. Chassis and body design will follow perforce in the direction of light weight. The saving of gasoline and tires will be a great boon to the industry. It is undesirable to leave this subject without definitely recalling attention to the fact that possibilities for easy riding qualities are not a function of the car weight. They are a function of the ratio of sprung to unsprung weight, and the possibilities for reduction of weight are fully as promising in one as in the other. The public fancy is vicarious, demanding variety of combination and style. We shall therefore continue with various combinations of cylinders and more or less varied body design. There is nothing vicarious, however, in the harmonious combination of engineering and economic requirements which demand radical reduction in weight without the sacrifice of comfort or reliability. When this demand is thoroughly recognized and met, it will be found that the cost of production, instead of increasing, will show a marked decline.

G. W. KLINGER:—For six months I have been balancing crankshafts and flywheels, both statically and dynamically. We have obtained crankshafts from various automobile manufacturers throughout the country, to investigate and balance. A number of the shafts appear to be

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too weak; they are not rigid enough in that they whip, which naturally causes them to rotate around a curved axis. The flywheels seem too heavy for the crankshafts, which causes torsional vibration, or increases the vibration. Mr. Lanchester, of England, who has made a device to eliminate the torsional vibrations, has not taken into consideration the fact that a crankshaft and a flywheel must first be balanced both statically and dynamically before all torsional vibrations can be eliminated. It is absolutely essential, before using an anti-torsional-vibration device, to balance both statically and dynamically the crankshaft with the flywheel.

L. H. POMEROY:—I am particularly interested to learn that Mr. Vincent thinks as I do about the possibilities of the L-head engine, and I venture to say that during the next twelve months more people will think as we do. Captain Brewer's remarks are more in the nature of an addition to the paper than a criticism thereof; I fully appreciate and endorse his viewpoint.

Mr. Klinger's contribution is, however, very pertinent. I take this opportunity of stating, as one representing Mr. Lanchester in this country, that he certainly has no illusions upon the subject of the relative importance of static and dynamic balance. The work of the Lanchester crankshaft damper is to eliminate periodic torsional vibration. It does not and is not intended to have any effect upon static or running balance. It is, of course, highly probable that a crankshaft incorrectly balanced would be more liable to periodic torsional vibration than one correctly balanced, but the difference would be one of degree only. It should also be pointed out that it is by no means easy to obtain correct rotary balance in machines where only the ends of the crankshaft are supported, so that the crankshaft is free to whip when rotating at anything like a high speed. It has always seemed to me essential that the crankshaft should be kept rigidly in line before any balancing operations are carried out. It is also of interest to notice that the addition of crankshaft counterweights has a very considerable tendency to increase torsional vibration effects, unless the crankshaft is increased in diameter to allow for the effect of the heavy masses distributed along its length.

I am interested to learn Mr. Kemble's experience in respect to narrow piston rings, as it confirms my own.

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STEAM AUTOMOTIVE SYSTEM

By Lewis L Scott[1]

It is stated that the general performance of the steam-propelled automobile has never been equalled by that of the most highly-developed multiple-cylinder gasoline cars and that it is significant that no innovation in the gasoline car has yet been able to give steam-car performance. This led to an effort to remove the troublesome features of the steam car, rather than to complicate the gasoline car further by attempting to make it duplicate steam-car performance. The paper describes in detail the steam automotive system developed by the author and E. C. Newcomb, including the boiler, the combustion system and its control, the engine and the condensing system.

It is generally conceded that so far as flexibility, smoothness of operation, simplicity of control, accelerating ability and high torque at low speeds are concerned the performance of the steam-propelled automobiles has never been equaled by that of the most highly developed multiple-cylinder gasoline cars. Yet when we consider the time required to raise steam, the expert attention and labor in operation, the short life of the boiler, the complicated and unreliable automatic devices, the danger from fire and explosion, the clogging of the burners, the short water-mileage, etc., it is easy to see why the automobile buyer has been willing to put up with even the one-cylinder gasoline car in preference to the steam vehicle.

Ever since the day of the one-cylinder automobile, designers have been trying to build gasoline cars that could approach the performance of the steam car. The result has been the addition of one complication after another, the twelve-cylinder engine being perhaps the final effort in this direction.

The significant thing, however, is that no innovation in the gasoline car line has been able as yet to deliver steam car performance. It appeared to me after an analysis of the situation that the obvious thing to do was to remove the troublesome features of the steam car, rather than add complications to the gasoline car in the effort to duplicate the performance of the steam car. In view

[1]Chief engineer, Standard Engineering Co., St. Louis, Mo.

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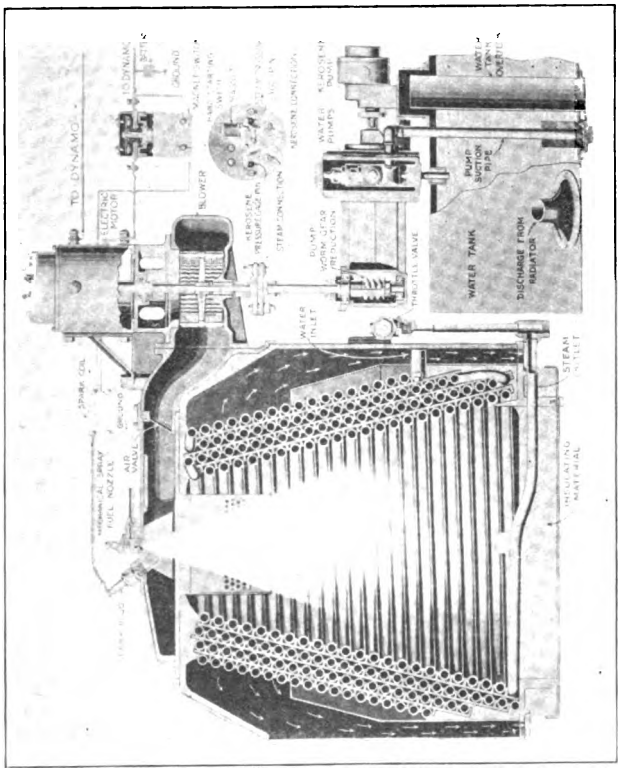

THE RELATIVE POSITION OF THE DIFFERENT PARTS OF THE SYSTEM

of these facts and of the present fuel situation, I believe that a description of the steam automotive system[3] developed by E. C. Newcomb and myself will prove of interest to engineers who are studying the problem of the use of steam at high pressures and temperatures, irrespective of its application to automobiles. While I will describe this system as applied to a motor car, it can be applied with equal advantage to a motor truck or tractor. This steam system has been in successful operation in an automobile for over one year. The following is a brief outline of what has been accomplished:

Steam can be raised from a cold boiler to a working pressure in about ½ min. No manual operation of

[3]Mr. Newcomb's first development work on the steam automobile was carried on from 1900 to 1906. One of his early steam cars was described in the *Horseless Age*, Jan. 28, 1903. This was the foundation work around which some parts of the present systems have been developed.

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any kind is required in starting, other than closing an electric switch

Only one kind of fuel is used, such as kerosene or heavier fuel. No pressure is carried in the fuel tank. The fuel is ignited in a cold state by a common spark-plug and is cleanly and completely burned. No vaporizing of fuel or pilot light is required

The boiler will not prime, is non-explosive, will not "crust-up" or scale and can be forced to any degree required in service. The car will run a mile on stored steam, after the fire is shut off. Spark-plug and boiler coil sooting troubles have been eliminated

All complicated automatic control devices have been eliminated. The steam-pressure gage is arranged to control the pressure and temperature of the steam automatically. All stuffing-boxes have been eliminated from the water-pumps and engine. The water-pump is noiseless in its operation. No cushion is required

The engine is of a highly efficient semi-uniflow type, having a steam rate of about 12 lb. per hp.-hr. It has only two cylinders and possesses a flexibility that cannot be approached with a twelve-cylinder gas engine. A condensing system gives long water mileage

The Boiler

The steam generator is of the continuous flow type and consists of four frustro-conical coils connected in series to form a continuous tube through which all of the water to the boiler and all of the steam discharged from the boiler must pass. The coils of this boiler are wound on a conical drum, one coil being wound right-hand and the adjacent coil left-hand. The coils are assembled one over the other and the ends are welded together. Spacers are used to separate the coils. Nickel steel tubing ½-in. inside diameter and ¾-in. outside diameter is used for the boiler coils. This tubing will withstand a pressure of about 35,000 lb. per sq. in. and cannot be injured in any way by freezing. All of the joints, which are very few, are welded.

Water enters the bottom of the outer coil, the coil most remote from the fire, and steam is discharged at the lowest point of the inner coil next to the fire. This construction causes the liquid supplied to the generator to flow gradually and uniformly from the outer coil toward the inner coil in a direction opposite to that of the flow of the products of combustion, and the liquid is gradually and uniformly heated and prevented from

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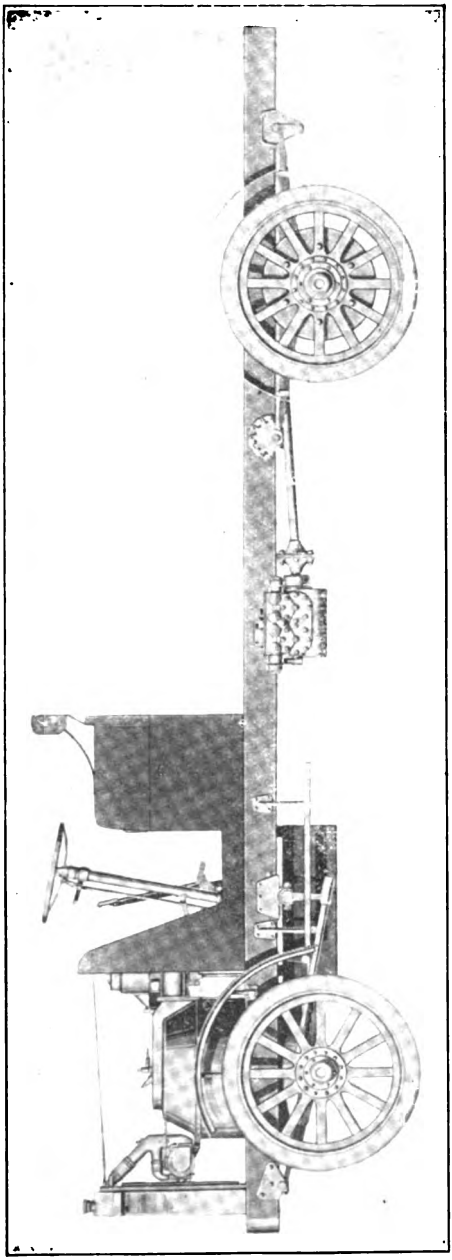

A 2-Ton Truck Equipped with the Steam System

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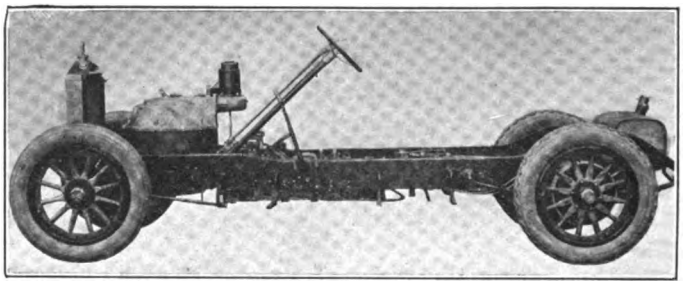

SIDE VIEW OF THE PASSENGER CAR
The Dynamo, Which Is Mounted Directly in Back of the Boiler, Determines the Height of the Dash

flowing by gravity to the inner coil or coils, as it would if the coils were arranged one above another.

The inner coil surrounds the combustion chamber, and the products of combustion as they pass between the coils are brought into contact with successively cooler heat-absorbing surfaces. Therefore, the available heat is nearly all absorbed. The stack temperature runs from 250 to 350 deg. fahr. It is not necessary to insulate the outer shell that covers the boiler coils. This shell can be removed in a few minutes, so that the coils are very accessible.

Circulation of water through the boiler is dependent upon action of the water-pump. The velocity of the steam through the boiler is approximately 450 ft. per sec. Owing to this high steam velocity and to the use of deflocculated graphite mixed with kerosene for lubricating the engine cylinders, scale and deposit troubles have been eliminated. Tubes sawed out of a boiler after one year's operation show no sign of deposit except for a very thin film of graphite on the inside. The boiler has about 72 sq. ft. of heating surface and can produce 500 lb. of steam per hr.

COMBUSTION SYSTEM

The fuel used is kerosene or fuel oil, carried in a tank at the rear of the car. No pressure is maintained in the fuel tank. When the fire is on, the fuel-pump, driven by a small electric motor which also drives the water-pump and air blower delivers fuel to a mechanical atomizing nozzle located at the top of the boiler, whence it is discharged at about 35-lb. pressure in a very fine spray downward into the combustion chamber. Attention is called to the fact that air from the blower has nothing

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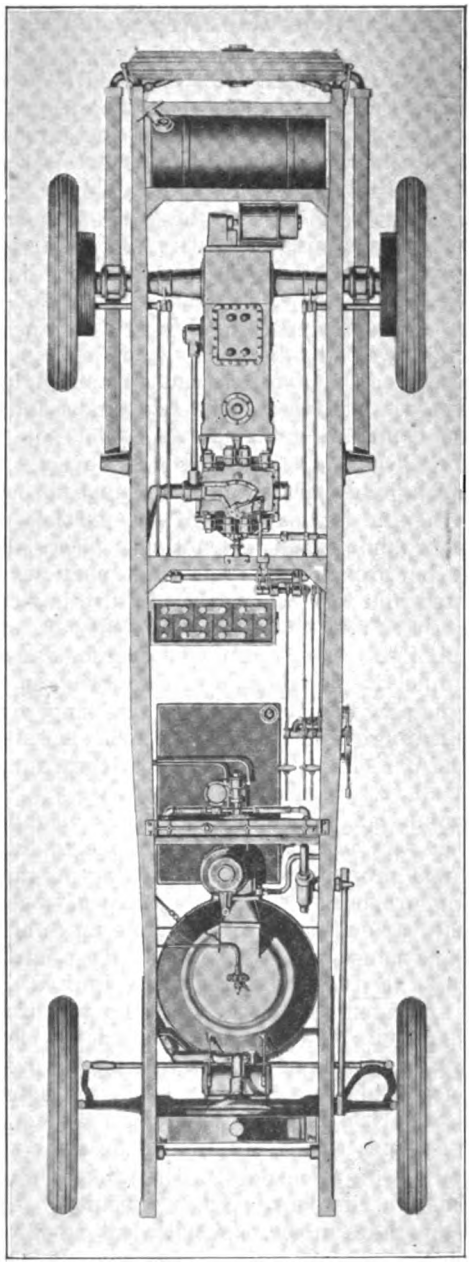

VIEW LOOKING DOWN ON A STEAM PASSENGER CAR

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to do with atomizing the fuel. The fuel is atomized by the pressure forcing it through a nozzle of special shape. This nozzle is arranged to prevent fuel from passing through it until proper spraying pressure is reached.

Ignition of the fuel spray is effected by a common spark-plug. The terminals of the spark-plug are located in a zone where the mixture is very rich. Air to support combustion is supplied by the blower. The ignition of cold kerosene by a spark and the efficient and complete burning of the fuel depend upon the size of the kerosene particles, their velocity, the quantity of heat in the spark and its location, the arrangement for supplying air to complete the combustion and the size, shape and arrangement of the combustion chamber.

If a particle of fuel of a given size moves at a certain velocity through an electric spark, it must absorb enough heat to bring the temperature of the particle up to the flash-point or combustion will not take place. Hence the fuel must be broken into very fine particles and the spark located in a zone where the mixture is rich. By so doing the spark-plug soon accumulates soot which will short-circuit it in a day's run. To overcome this trouble a short funnel is placed around the spray and the terminals of the plug, which are made extra long, are allowed to project through a hole in the funnel. An air space is between the porcelain of the plug and the funnel. This eliminates all trouble from soot deposits.

The combustion of atomized fuel is usually accompanied by a very objectionable roar, due to the varying rate of flame propagation in a mixture of gas and air of changing proportions. In a mixture of constant proportions the various parts of the flame move at different velocities and cause a similar noise. To secure a rapid reaction of the fuel mixture when ignited, a double funnel is arranged to project into the top of the combustion chamber. The funnels are made of sheet nickel about 1/32 in. thick. While the temperature at this point is not high, the funnels heat up instantly and catch and vaporize all stray particles of fuel. The use of the funnels practically eliminates the noise.

The burning of atomized fuel requires the use of a long combustion chamber. Great difficulty has been experienced by others in the past with failure of refractory linings on account of flame impingement. It is necessary that combustion be complete before the fire touches the boiler tubes or deposits of soot will form. With the

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combustion chamber as shown in the sectional view of the boiler, the fire cannot play on any coil and the heat is gradually absorbed over a large area, with the result that no trouble is experienced in burning boiler coils or breaking down the refractory lining. The combustion chamber is surrounded by the boiler coils.

The air-valve or shutter in the blower discharge line opens when the blower is running and closes by gravity when the blower stops. It prevents back-flow of heat from the combustion chamber when the blower is not in operation.

Under normal operation the temperature of the inner boiler coil never rises above 800 deg. fahr., and the coil is therefore not subject to the oxidation which would result at higher temperatures.

In some boilers we have coated the inner coil with aluminum and then purposely subjected it to temperatures ranging from 1400 to 1800 deg. fahr. It is surprising how this coating prevents oxidation at high temperatures.

Combustion Control System

Great difficulty has heretofore been experienced in maintaining an even pressure and temperature in the automotive use of the continuous-flow type of boiler. Pressures and temperatures either too high or too low lead to burning of boiler tubes, burning out of packing and to irregular running of the car. Control systems of the past included numerous by-pass, steam automatic and low-water automatic valves, flow meter, etc., all of which were delicate, unreliable and sluggish in action. The control we have developed consists of a steam-pressure gage which operates an electric switch that in turn controls the operation of a small electric motor. As the water and fuel-pumps are driven by the same electric motor, these liquids are pumped in unison and in a definite quantitative relation. For this reason superheated steam is delivered at a temperature and pressure ratio which is substantially unvarying. As the fuel and water-pumps are put into action almost instantly, they adjust themselves with great precision to meet situations in which the demand for power varies greatly and the variations are sudden and irregular.

The length of time that the motor is running depends upon the demand for steam. If for example the car is running at 25 m.p.h. on a level road, the motor will run

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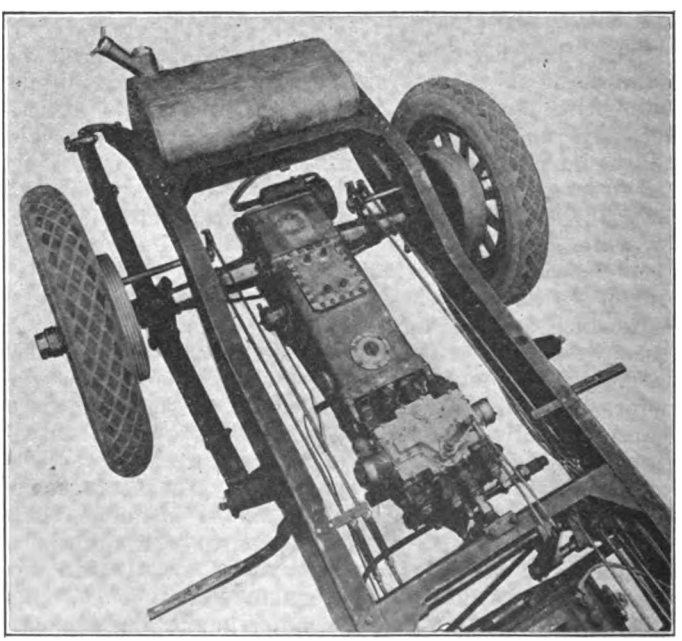
and the fire be on about one-third of the time. If running up a hill at the same speed, the fire might be on all the time. If running at 60 m.p.h. on a level road the fire would be on all the time. Thus it is easy to see the advantage of using a constant-speed electric motor in place of driving the pumps from the engine. This drive has also the advantage of locating right at the boiler all parts containing water. By driving the water-pump with an electric motor it is not necessary to use a cushion in the water line to prevent water hammer. In former practice these cushions usually took the form of spring-loaded pistons, which constantly broke springs and needed repacking. The safety or blow-off valve has been eliminated and is replaced by a fuse in the motor circuit. Should the automatic switch controlling the motor fail to cut out at the predetermined maximum pressure the motor will be compelled to pump against a greater pressure and the overload thus applied will cause the fuse to blow.

The starting and stopping of the pump motor is con-



THE ENGINE OF THE PASSENGER CAR IS MOUNTED PARTLY ON THE REAR AXLE AND PARTLY ON THE FRAME

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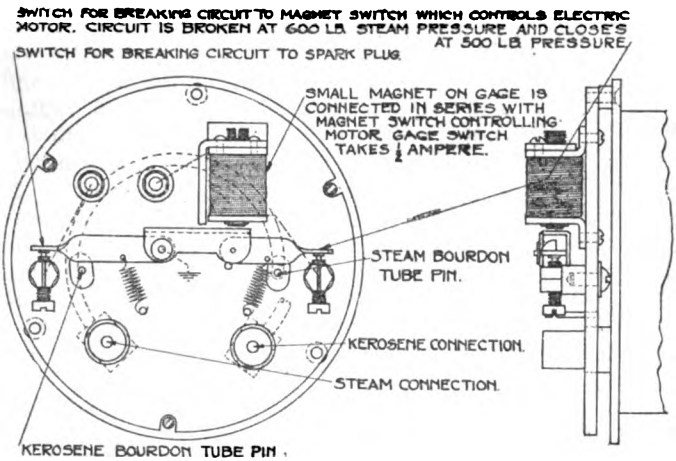
SWITCH FOR BREAKING CIRCUIT TO MAGNET SWITCH WHICH CONTROLS ELECTRIC MOTOR. CIRCUIT IS BROKEN AT 600 LB. STEAM PRESSURE AND CLOSES AT 500 LB. PRESSURE.
SWITCH FOR BREAKING CIRCUIT TO SPARK PLUG.
SMALL MAGNET ON GAGE IS CONNECTED IN SERIES WITH MAGNET SWITCH CONTROLLING MOTOR. GAGE SWITCH TAKES ½ AMPERE.
STEAM BOURDON TUBE PIN.
KEROSENE CONNECTION.
STEAM CONNECTION.
KEROSENE BOURDON TUBE PIN.

DUPLEX STEAM AND KEROSENE GAGE

trolled by the steam-pressure gage. This gage operates a small switch which is set to open the motor circuit at 600-lb. steam pressure and to close the circuit when the steam pressure has dropped to 500 lb. It is necessary to break the circuit at one steam pressure and close it at a lower one. This differential action is brought about by two forces; one, a small magnet on the back of the steam gage, the other, a pin on the Bourdon tube of the gage. At the time the switch is closed the water and fuel-pumps, air blower and spark-plug all operate in unison. The kerosene and steam gages are united in duplex form. The back of this duplex gage is shown. Small pins which are attached to the Bourdon tubes of these gages project out through the back of the gage and operate the small electric switches. The kerosene gage controls the time of operation of the spark-plug. This circuit is closed from 0 to 25 lb. pressure or during the time immediately following the starting of the motor, and open above 25-lb. pressure, thus shutting off the spark after the fire is lighted. The normal pressure on the delivery side of the fuel-pump, when the motor is running, is about 35 lb. A constriction at the gage introduces a time element such that the pressure in the Bourdon tube of the gage does not build up immediately upon starting of the fuel-pump. The spark coil is connected to the motor side of the magnet switch and the spark is therefore off when the steam pressure is up to 600 lb. If for any reason the spark should fail and the combustible mixture fill the

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combustion chamber and be later ignited, no more harm is caused than by a muffler-explosion in a gas car.

To avoid handling the motor current on the steam-gage switch, and to get a quick-acting switch in the motor circuit, a magnet switch is used to control the motor circuit. The magnet switch takes ½ amp. to operate it and this is the current carried by the gage switch. A steam temperature gage is used to indicate the temperature of the steam, which runs from 600 to 750 deg. fahr. This gage has an electric switch that closes at 800 deg. fahr. at which time the fuel will be automatically cut off from the combustion chamber. The closing of this switch causes a small magnetically-operated by-pass valve in the fuel line to open. This switch seldom comes into use in the normal working of the system, but is a safety means to shut off the fire in the event that the water-tank is empty. It is also a means of correcting the fuel-water ratio if this should for any reason be deranged.

As with most gas cars, we use an electric motor, a storage battery and a generator. The motor and generator have compound windings, and the series fields of the motor and generator are connected in series. The generator furnishes all of the current to the motor direct when the engine is running; when the motor shuts off, due to steam pressure being up to 600 lb., the series field of the generator is automatically cut out, thereby reducing the output to a current suitable for charging the battery. For tractor work, where the speed of the engine is nearly constant, it is possible to eliminate the generator, motor and storage battery, but it is then necessary to have hand starting devices, a dry battery for ignition and control of small magnets which act on the suction valves of the pumps. For passenger-car applications the motor and storage battery are believed to be the most direct and simple arrangement.

One of the sources of trouble on automotive steam systems of the past was the water-pump. It was noisy, valves would not last very long, it would become air-bound when the water in the tank became too hot and required a constant adjustment of the stuffing-boxes. The valves on the water-pump used in this instance are made of special non-rusting material that has very long life. The lift of the valves is limited to 1/16 in. Because of the small lift and special design of the valve and the fact that the pump always runs at the same speed, regardless of the speed of the car, all pump noise is eliminated. As

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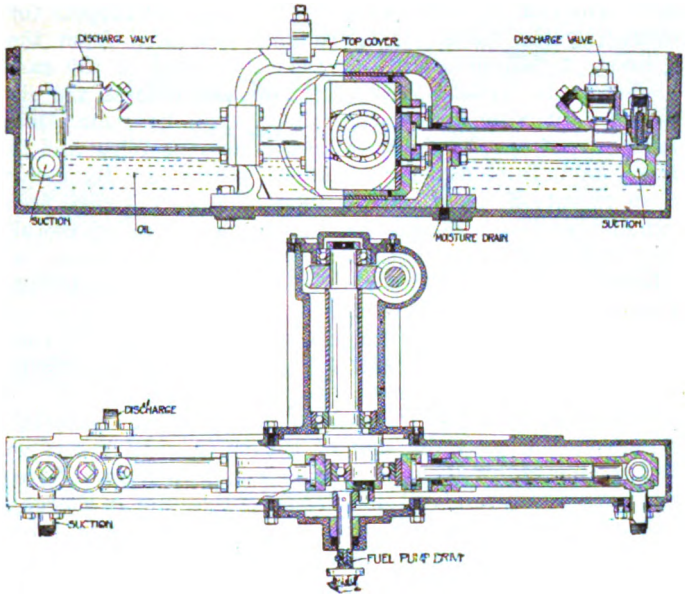

SECTIONAL VIEWS OF THE WATER-PUMP SHOWING THE WORM GEAR DRIVE

the pump has practically no clearance space it cannot become air-bound. No stuffing-box is used and the entire pump is enclosed in a case and submerged in oil. The pump plunger is made of hardened high-chromium steel; it is designed so that there can never be any side-thrust on it or on the pump cylinder and consequently there is absolute alignment at all times. By making the pump cylinder long and the bore absolutely round and straight, the wear of the plunger or the cylinder is substantially nil, there is no need of using stuffing-boxes, and a minimum amount of friction between plunger and cylinder results. The pump does not leak. These pumps have been built to work successfully against 5000-lb. pressure although the pressure in this instance never exceeds 600 lb.

THE ENGINE

The engine is of the semi-uniflow two-cylinder double-acting poppet-valve type. The valves and piston-rods are made of non-rusting material and the former never need to be reground. The metal in the cylinder is absolutely uniform in section, so as to insure even expansion when

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hot. The cam box, which carries the cam and tappets for operating the valves, is thoroughly insulated from the cylinder to avoid heating of the oil carried in the cam housing. Different points of cut-off and reverse are obtained by moving the camshaft in an axial direction. The cams are of special shape to permit easy shifting and to allow an infinite number of cut-off positions. By using a short cut-off, tight valves, small clearance space, free exhaust and a uniform section of the cylinder metal, very low steam consumption is secured. The mechanical efficiency of the engine is about 95 per cent. No stuffing-boxes are used on valve-stems or piston-rods, these being unnecessary because of the use of non-rusting material, proper design and workmanship and means for maintaining perfect alignment.

The throttle-valve is made of non-rusting material. Steam cannot pass the seat of the valve until the valve is far enough off its seat to give a full opening. Wire-drawing which tends to destroy the valve seat is thereby prevented. The throttle-valve is arranged to close automatically when the brake is applied.

In passenger cars the engine is mounted partly on the rear axle and partly on the frame, the greater portion of the weight being carried by the frame. The unsprung weight on the axle is small. By employing this construction the drive-shaft and universal-joints are eliminated and a smooth-riding car is obtained. In the case of truck applications the engine is mounted on the frame of the car, and a conventional rear axle used.

After steam is up the engine and car are started forward and the speed controlled by opening the throttle-valve. The cut-off position is controlled by a pedal connected so as to move the camshaft axially. The same pedal is also used to shift the camshaft to the reverse position, when backing the car.

When the engine is mounted partly on the rear axle and partly on the frame, the differential spur gear is carried in the engine case. This is an aluminum casting carefully designed to take care of all conditions met in service. There are many unique features in the differential, the principal one being the means of adjusting the differential spur gear to the engine spur gear. This adjustment is brought about by having the bearing for the axle mounted in the aluminum frame on an adjustable axis of rotation which is eccentric to the axis of the axle. This arrangement permits a very fine adjustment

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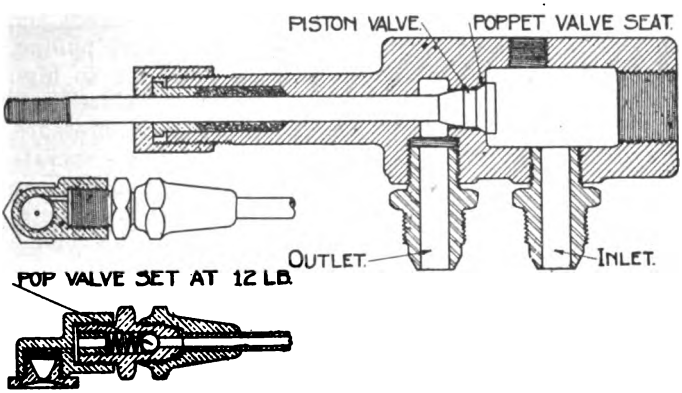

THE THROTTLE VALVE (ABOVE) AND THE FUEL SPRAY NOZZLE (BELOW)

between the engine driving-gear and the differential gear and maintains a concentric alignment of the entire axle.

CONDENSING SYSTEM

It is possible to obtain a water-mileage of from 100 to 350 on a 25-gal. tank of water by simply running the exhaust steam from the engine into the top of a radiator which is similar to a gas car radiator and connecting the bottom with the water tank; this is without using a radiator fan. Weather and road conditions will greatly affect the water-mileage. It is very desirable to get great water-mileage because aside from general inconvenience the amount of foreign matter brought into the system is greatly reduced. Great water-mileage will admit of the use of alcohol in the water to prevent freezing in cold weather. One of the first things to accomplish in this matter is to have an engine that is efficient. The efficiency of the engine not only saves fuel and water but determines the size of the boiler. The exhaust steam from the engine must be properly distributed at the top of the radiator and the discharge from the radiator to the water tank must be distributed to prevent noise. It is desirable to have a radiator fan driven by the exhaust steam from the engine. If the fan is mechanically driven from the engine it will not do very much good on long hills or on heavy pulling where the car is moved slowly and the steam consumption is large. The ordinary exhaust turbine will not do for this work on account of the constantly changing load. If the turbine nozzles are set

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so that the turbine will run at average road speeds and the car is operated at higher speeds or in heavy pulling, the back-pressure on the exhaust line will be so high that the engine power will be materially reduced. If the nozzle area is set to keep down the back-pressure, the turbine will not run except when the engine is operating under a heavy load. We have experimented with an exhaust actuated turbine which is provided with automatic means for increasing the nozzle area as the volume of steam increases, thereby keeping the steam velocity approximately constant irrespective of variation in steam volume.

It is probably not generally known that a properly designed automotive steam plant using steam at 600-lb. pressure and 700 deg. fahr. temperature has a total efficiency at the rear wheels of about 15 per cent or more. While this is slightly below the full-load efficiency of the average gasoline car, it must be kept in mind that the efficiency of the internal-combustion engine is at its maximum only at full engine power. This is not true with the steam engine, in which the efficiency increases as the load decreases. Most automobile engines run at about one-fourth load the greater part of the time, and under this condition the efficiency of the steam engine is much above that of the gas engine plant. We have obtained from 12 to 15 miles from a gallon of kerosene under average road conditions with seven passengers in a car weighing without load 4200 lb.

In a recent test this car ran 1325 miles on a 25-gal. tank of water, or about 53 miles per gal. of water. The car was driven at speeds of 25 to 35 m.p.h. over average St. Louis County, Mo., roads, and averaged slightly over 12 miles per gal. of kerosene. The temperature of water in the water tank at the end of a long run is 130 deg.

THE DISCUSSION

A MEMBER:—Regarding the nozzle, what pressure is used in atomizing the oil?

L. L. SCOTT:—We use 35-lb. pressure; the oil will atomize at 10 lb.

A MEMBER:—What diameter has the hole at the end of the nozzle?

MR. SCOTT:—That depends upon the quantity of fuel we wish to burn. We have burned as high as 70 lb. per

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hr. In that case, we use about a 0.04-in. nozzle at 35-lb. pressure.

E. F. ANDREWS:—Is there not an objection to using an electric motor to drive the water-pump of a steam automobile? The pump requires considerable power and to transform from mechanical into electrical energy and back again is rather an inefficient means of driving. There are great advantages, unquestionably, in using an electric motor to drive the pump, but to what extent do the pump-driving losses offset these advantages?

MR. SCOTT:—The electric drive is equally as efficient as a direct drive from the engine, for several reasons. One is that in driving water-pumps from the engine energy is being wasted in pumping water that is by-passed, because the engine is running all of the time the car is running and water is being pumped. But with the electric drive, when the motor is running all of the water being pumped is used; none of it is by-passed. Further, the electric motor for driving the water-pump, the fuel-pump and the air-blower, in the normal-sized car, takes about 0.75 hp. The dynamo and the motor each have a compound winding. The series fields of the motor and dynamo are connected in series. When the fire is on and the car is running, the dynamo furnishes current direct to the motor; there is no loss through a storage battery. When the motor cuts off automatically, due to high steam pressure, the dynamo output is automatically cut down to a current suitable for charging the storage battery because the series field is cut out. The electrical unit in this system is very little, if any, larger than the ordinary dynamo and motor used on a gasoline car.

A MEMBER:—Have you ever used any other means than the spark-plug for igniting the oil, such as winding leather with nickel wire, bringing it to an incandescent heat?

MR. SCOTT:—No. We found the common spark-plug very satisfactory and have never had occasion to use anything else.

A MEMBER:—Have you tried that to avoid sooting trouble?

MR. SCOTT:—We have no sooting trouble.

B. F. TILLSON:—I would like to ask Mr. Scott to contribute for publication in the TRANSACTIONS some more complete engineering tests, in regard to boiler and engine efficiencies and the temperature of the gases leaving this boiler. These would form a basis that could be used in

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a rough-and-ready manner in checking against too high efficiencies. There have been steam cars in the past in which the engine efficiencies, as noted in the discussion in the TRANSACTIONS, did not check up, or the boiler efficiencies failed to check up with the temperature of the leaving gases; and there is an inevitable amount of heat lost. An idea of the fuel oil consumption per boiler horsepower would be of interest. I understood that the rating of the boiler is 500 lb. of steam per hr., from and at 212 deg. fahr., which would be a 14.5-hp. rating of the boiler. Mr. Scott said that 72 sq. ft. was the surface of the boiler tubes.

How heavy an oil has been used successfully by a mechanical atomizing burner without difficulty in clogging the burner?

W. C. KEYS:—What is the composition of this tube? It is nickel steel, I take it.

C. W. SPICER:—The paper explains what happens if too large a proportion of fuel is supplied; but what happens if the supply of fuel is inadequate? There are extreme conditions; for instance, when a doctor is making calls about town on a cold windy day, his car stands out in a blizzard for an hour or more, he travels perhaps 5 min. to the next call and then the car stands another hour. The fuel required to make up for loss from radiation might be considerable when no corresponding amount of steam was required. How do the automatic features meet that condition.

HENRI G. CHATAIN:—I agree with Mr. Scott's statements to such an extent that constructive criticism becomes difficult because it bears largely upon details. I believe Mr. Newcomb first worked along the line indicated in about 1900, and did not recommend the system of direct proportioning of both water and fuel control as advocated at present. Do these proportions remain constant in actual operation? If not, how can the disproportioning be corrected so as to preclude the possibility of a too cold boiler, considering that the amount of water evaporated per square foot is not, throughout the range of operations, proportional to the fuel burned? With the system of parallel control of water and steam, is the degree of superheat maintained reasonably well?

Has Mr. Scott made investigations, which would be at all conclusive, leading to the determination of what percentage of the boiler tube is filled with water, what percentage contains steam and whether this varies at dif-

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ferent rates of output? To my knowledge none of the earlier investigators attempted this determination, but it would be an excellent thing to know, so that in designing a boiler one could preclude the possibility of having the influence of gravity bring water down into the steam part of the coil, thereby raising the pressure when it is not wanted.

In the particular boiler just described, what is the cubic space of the combustion chamber, or has the cubic space required to properly burn a unit of fuel been determined? In the early days this space varied considerably, apparently according to the fancy of the designer, but today there seems to be a general trend toward making this space considerably larger.

Has the make-and-break plug such as was formerly manufactured by the Bosch company and used with the Honold system been tried? It seems to me that this type of plug offers qualifications for this particular class of work which would be far superior to the high-tension variety. We have used these plugs to a considerable extent in internal-combustion engines and find that they are much more reliable under sooty conditions than the high-tension plug. Their inability to function at extreme high speeds and the excessive wear of both the "hammer" and "anvil" were their only faults. Used for the ignition of fuel in a steam automotive system, these faults would not be manifest and it would appear that their qualifications to work under sooty conditions would make their use highly desirable.

Summing up many tests which we have made, we find that the maximum evaporation per pound of fuel is from 13 to 13½ lb. and this was obtained when an evaporation of approximately 7½ lb. per sq. ft. of heating surface was effected. A superheat of 100 to 200 deg. fahr. was maintained. When the evaporation was forced beyond this point, the pounds of water evaporated per pound of fuel fell below 13. These results, which no doubt Mr. Scott has attained or even improved upon, when considered in conjunction with his statement of a brake horsepower for 12 lb. of water, show that a brake-horsepower-hour can be obtained with the steam automotive system for something less than 1 lb. of fuel. This fact, considered with the better efficiency of the steam engine at fractional loads, makes the system compare favorably with the best gasoline-engine practice.

MR. SCOTT:—In regard to boiler and engine tests, it

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will be out of the question to go into detail more than to say that in our boiler the efficiency varies from 75 to 85 per cent, under varying loads and conditions, and the steam consumption of the engine varies from 12 to 15 lb. per hp.hr. The temperature of the gases, the stack temperature, varies from 250 to 300 deg. as was stated.

Regarding the gravity of the oil fuel, while we have made tests in our laboratory on fuel oil and gas oil, we have never used those in the car; we have used only commercial kerosene.

The question about burner clogging evidently refers to the small fuel nozzle. Where the fuel is properly screened, we have no more trouble in that respect than with the ordinary carbureter. The opening is equally as large as that in the carbureter and it has given us no trouble.

With regard to the analysis of the tubing, we have used ordinary 3½ per cent nickel tubing. We do not know that it is any better than ordinary tubing. As I have stated, we have tried boiler coils in which the inner boiler coil was calorized, by a treatment developed by the General Electric Co. for the purpose of preventing oxidation at high temperatures. The question as to whether that is needed is still undetermined. If so, the cost is very low.

In reference to the fuel-water ratio, we have the fuel slightly in excess of the water. The ratio in our boiler varies between 1 to 10 and 1 to 13. We run the fuel slightly in excess of the water which, under extremely heavy loads, will cause the temperature to sometimes reach 800 deg. At this time the fuel is automatically cut off and the water continues to be pumped into the boiler, providing the steam pressure is below normal. Our steam pressure and temperature, as a whole, is very steady and holds very well. Under light driving conditions when starting the boiler from cold, the steam temperature will probably be 500 deg. fahr.; after 5-min. running it will get up to 650, 700 or 750 deg. and stay there. Under very heavy loads, it will sometimes get as high as 800 deg. and cut off. We have no trouble with steam at this temperature. As far as lubrication trouble is concerned we use deflocculated graphite, and our engine is a poppet-valve type, which is suitable for high temperature.

Mr. Newcomb worked intermittently on the steam automobile from 1900 to 1908. I have never heard Mr.

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Newcomb say that he did not advocate the system that we are using today. This system, or idea, of pumping water and fuel in definite quantitative relation was a fundamental idea of Mr. Newcomb's. We have applied it in a different way; that is, we have an electric control and an electric drive for the fuel and water-pumps.

We have never experienced any trouble in having too cold a boiler; if the fuel line is stopped up, the fuel and water ratio will change and the steam temperature will be lowered. With this system of control the temperature of the steam remains within 100 deg.; under ordinary driving conditions, it will hold very closely within 20 deg.

Referring to the portion of the boiler tube that is filled with water, I have never experimented with this. From what I learned from Mr. Newcomb I would say the first and second outer coils, referring to the illustration in the paper, are filled with water; the third is the vaporizing coil and a part of the fourth is the super-heating coil. The thing that I want to emphasize particularly concerning a fire of the atomized type is the size of the combustion chamber. The point was raised whether there is any definite size or figure. With a fire of the atomized type it is necessary to have a considerably larger space in which to burn the fuel than with a fire of the vaporized type, which has been on all automobiles of the past. The reason is that with the atomized type of fire the fuel is ultimately vaporized in suspension.

The flow of water by gravity from one coil to another is prevented by the boiler connections. The water enters the bottom of the outside coil and flows upward to the next coil.

We have not tried the make-and-break spark-plug for the reason that we found the jump spark to be perfectly satisfactory and were satisfied to let well enough alone. It is not necessary to have any tight joints in a spark-plug in this system, as in the case of the gas engine, because we have no pressures to deal with; the spark gap can be considerably larger, because we are not working against any pressure. We formerly had sooting trouble, but overcame it in the way already described.

It is possible to evaporate 13½ lb. of water with 1 lb. of fuel and get a superheat of 100 to 200 deg. fahr. When we overload the boiler or force it beyond its normal working condition, the ratio may change to as low as 1 lb. of fuel to 10 lb. of water. This ratio will change slightly according to different loads, but the change is not enough to affect the situation seriously.

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PREIGNITION AND SPARK-PLUGS

By Stanwood W Sparrow[1]

The author proposes to determine what features of spark-plug construction cause preignition and how this preignition manifests itself. To this end observed conditions on an Hispano-Suiza aviation engine following 4 hr. of an intended 6-hr. run are reported, with supplementary tests and observations. This resulted in experiments made to determine the cause of preignition, using spark-plugs constructed so that different features of their design were exaggerated. Illustrations of these plugs are shown and the results obtained from their tests are described. The different observed peculiarities are then stated, analyzed and compared with normal spark-plug performance. The experiments serve as a means of identification of special forms of preignition and as an indication of the abnormally high temperatures to which valves and combustion-chamber walls are thus subjected. They also serve as a basis for predicting the performance of a given design of spark-plug or for designing a spark-plug to meet known conditions.

What features of spark-plug construction cause preignition and how does this preignition manifest itself? These two questions this paper proposes to answer. There seems to be no better way of describing the particular phases to be treated than to tell of the events that led us to undertake the work.

After about 4 hr. of what was intended to be a 6-hr. test of a 180-hp. Hispano-Suiza aviation engine, the flame from one of the exhaust ports was noticed to be about twice its usual length and of that light-yellow color which usually indicates a rich mixture. At the same time the power of the engine decreased about 10 per cent, vibration was much increased and the exhaust valve appeared to be extremely hot. The engine was stopped and inspected as thoroughly as possible without dismantling, but except that the spark-plugs were badly carbonized no trouble was found. With new spark-plugs the engine not only completed this run, but made several later runs without any recurrence of this trouble. It should be borne in mind that no adjustments had been

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made of mixture ratio or throttle during the 4 hr. prior to the appearance of this long yellow flame and that the engine had been developing about 140 hp. during this time. Some weeks later the phenomena again appeared. Temperature measurements were made at this time with a thermocouple inserted in one of the spark-plug holes. This couple showed an average temperature of 150 deg. cent. (392 deg. fahr.) with normal operation of the engine and 400 deg. cent. (752 deg. fahr.) with preignition. The couples used were not constructed for these tests and the actual temperatures have no particular significance as they are temperatures of a part of the cylinder wall thermally insulated from the jacket. It is the relative temperature that is important, noting that at the time the flame appeared and the power decreased the temperature was much greater than during normal operation. This was confirmed by the fact that when the engine was stopped after a few minutes operation, the exhaust valve in a cylinder that had been preigniting would remain red for nearly a minute after the valves in all the other cylinders had become black. Experiments were then begun to determine the cause of this occurrence and the results of this work are here summarized.

What Is Preignition

Whenever a spark-plug is referred to in this paper as causing preignition, it is the effect of preignition just described that is meant, the long yellow flame, engine vibration, drop in power and extreme heat. The first task is then to show that preignition does produce this effect and to define just what is meant by preignition. Although preignition is quite commonly defined as "self-ignition from the heat of compression," in this case the literal meaning of the word has been more closely adhered to and it has been called ignition from any cause before the proper time, or the time of ignition which will result in maximum power production. It was not difficult to determine that preignition would cause the above noted effects. This was accomplished experimentally by setting one of the two magnetos successively ahead by 15-deg. steps, with the high-tension wire from this magneto disconnected from all but one cylinder. This magneto was not switched in until the engine had been brought up to speed on the other set of plugs. By changing the wires the effect of the advance could be studied in any cylinder. The magnetos are set for an advance

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of about 20 deg. ordinarily and it was found that firing from about 65 to 215 deg. before center did produce the effects I have described, including the long yellow flame. The intensity of the flame seemed greatest at an advance about midway between these two points and was about the same for all cylinders.

It is evident then that this trouble is caused by preignition. It remains to determine just how the sparkplugs cause preignition. The line of investigation followed was to construct plugs in which different features were exaggerated. The accompanying sketches illustrate some of these plugs. No special significance attaches to the exact shape of the porcelain or the shell. The plugs in which the special features were incorporated were of two types that have been used with satisfaction in the laboratory and in actual service; and, since both would produce the results noted, the drawings have been made to show approximately the average proportions of these two plugs.

The first definite indication as to the cause of the trouble came with a plug having the so-called petticoat type of porcelain, the lower end of the petticoat in this case having been broken off so that it rested near the center electrode in about the position shown in Fig. 2. This plug produced preignition when used successively in four different cylinders. Moreover, removal of the piece of porcelain broken off cured the trouble and its substitution on a standard one-piece plug, as illustrated in Fig. 2, again produced it. It would be assumed from this that either the porcelain becomes hot and fires the incoming charge, or that it is instrumental in heating the center electrode to the igniting temperature. A happy accident at this point gave considerable aid. The bit of porcelain slipped into the position shown in Fig. 1, while being inserted in the cylinder and in that position operated without preignition. This pointed to the heating of the center electrode as being the root of the trouble, even though this heating effect be of no great magnitude. Further experiments have supported this supposition, as regards both the cause of the trouble and the narrow range existing between normal operation and preignition. Thus, the plug shown in Fig. 3, with a piece of porcelain wedged between the center and the side electrodes will persistently cause trouble; while with the piece removed the plug will operate satisfactorily. The breaking away of a large portion of the porcelain

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from around the center electrode will not change the operation of the plug.

If a plug porcelain be cracked as shown in Fig. 4, so that the break can be detected only by the fact that the center electrode can be moved with the finger, preignition will result. If now the porcelain be broken away, leaving the center electrode bare down to the crack, the plug will again operate without trouble.

Fig. 5 shows a plug upon the center electrode of which has been placed a metal disk of about 5/16-in. diameter and 7/64 in. thick; the spark jumping the annular gap. The plug so constructed caused preignition, but with the disk removed or with one side of the disk flattened as

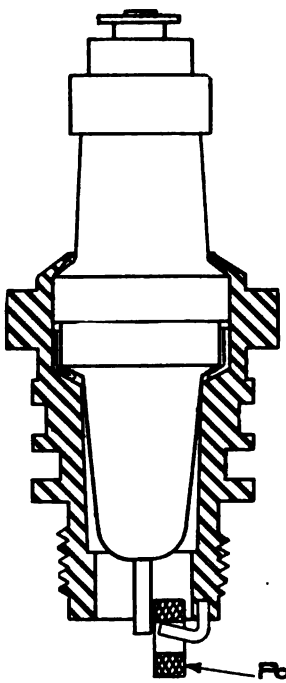

FIG. 1

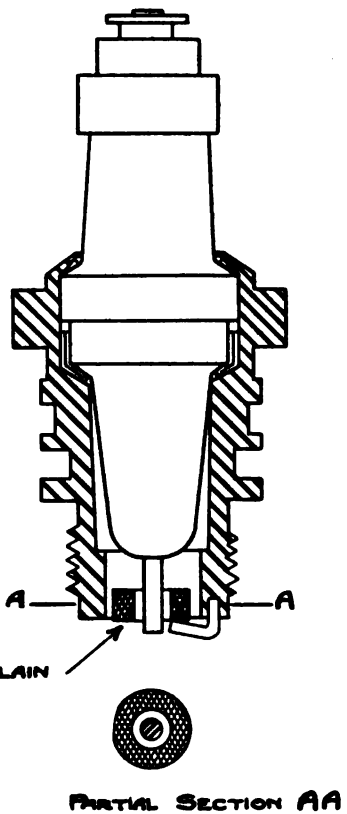

FIG. 2

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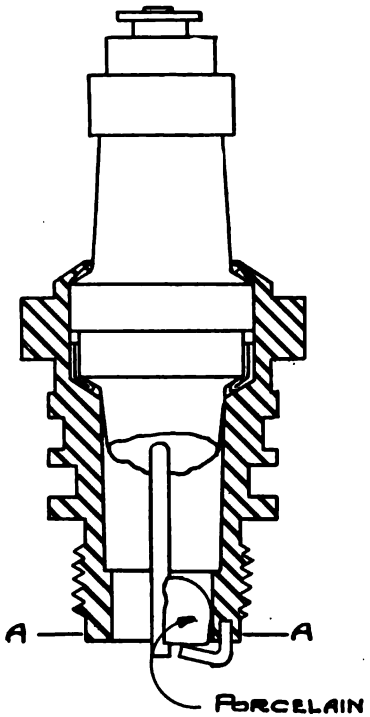

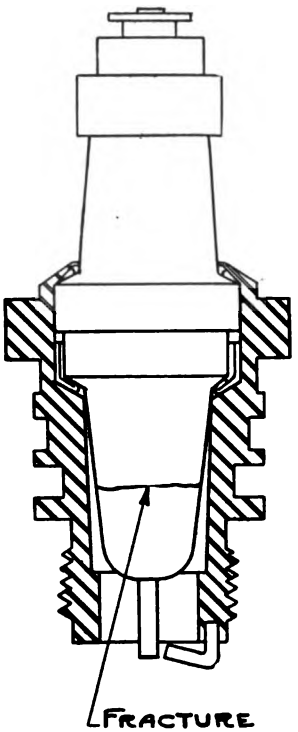

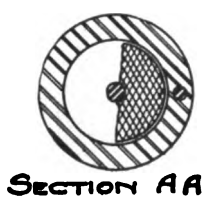

FIG. 3

FIG. 4

in Fig. 6, it operated normally. Fig. 7 illustrates another case where the line dividing preignition from satisfactory operation is extremely narrow. The plug is unusual only in the respect that the side electrode is replaced by a circular bushing of brass. Several were made leaving the bushing a slip-fit to the shell, all of them causing trouble, while others having the bushing a drive-fit to the shell operated satisfactorily, apparently because of the better heat conduction in the latter case.

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What Causes Preignition

Thus far the types have been selected that were of most aid in fixing the cause of the trouble. That cause is an overheated center electrode which preignites the incoming charge and soon causes continuous burning throughout the cycle, extremely high average cylinder-temperature and loss in power. Further examination of the distinctive features of the plugs mentioned thus far shows in each case that these features do cause heating of the center electrode. It would be more direct

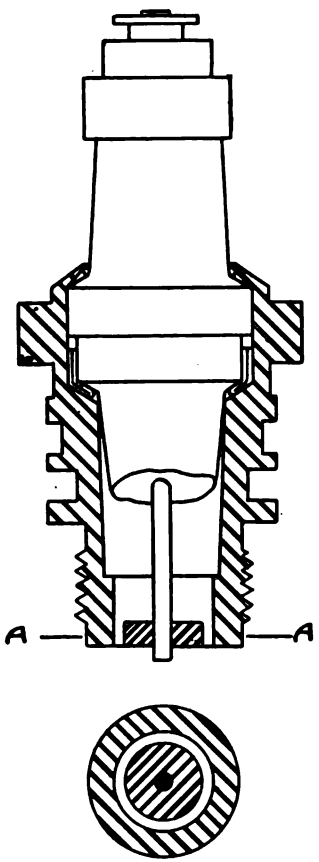

Fig. 5

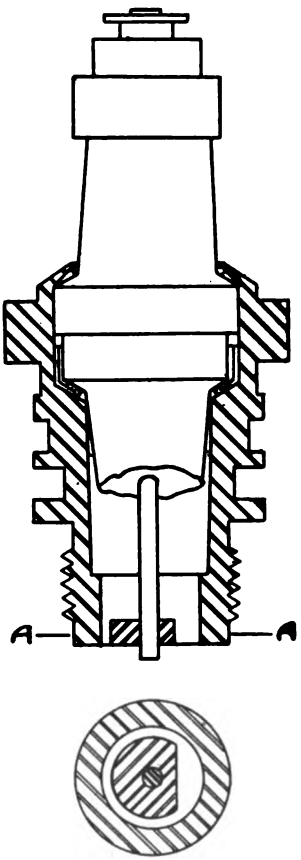

Fig. 6

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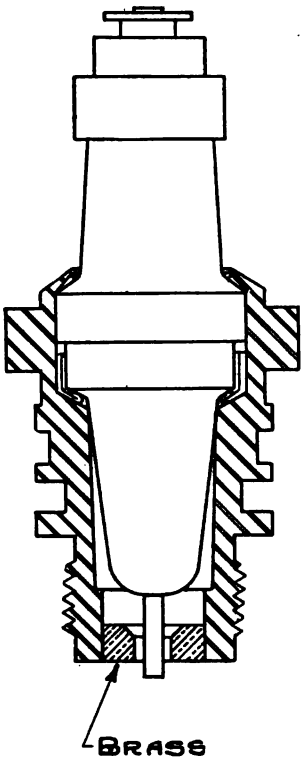

FIG. 7

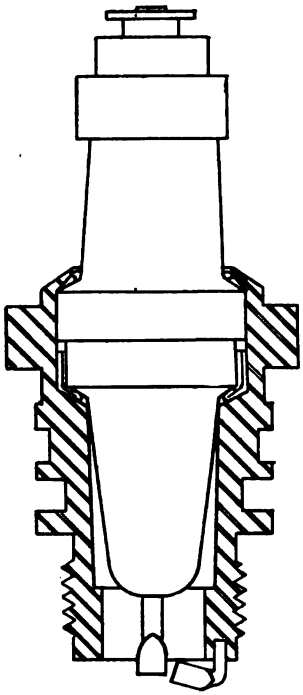

FIG. 8

to say that they prevent the cooling of the center electrode, through preventing its free contact with the cool incoming charge. It is not possible, however, to state whether the trouble produced by the fracture in Fig. 4 is due to the decrease in the heat conducted away by the porcelain or to the free access given to the hot gases by the burning away of the cement around the center electrode.

It is of interest to study a few of the other freak plugs tried in this series. Fig. 8 shows a plug with the electrodes flattened nearly to a knife-edge without producing trouble. Fig. 9 shows an ordinary plug to which has been added a loop of 1/32-in. steel wire extending into the cylinder 2 3/16 in. from the shell. Here again, although there is a wire that doubtless becomes extremely hot, the fact that it is so freely exposed to the incoming cool gases prevents it from attaining an average temper-

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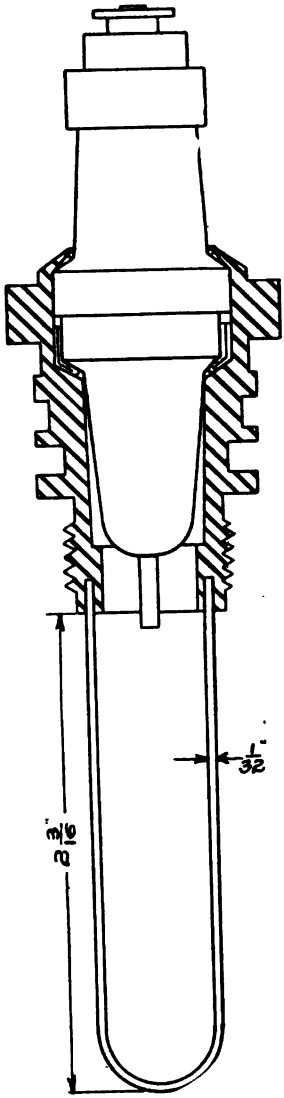

FIG. 9

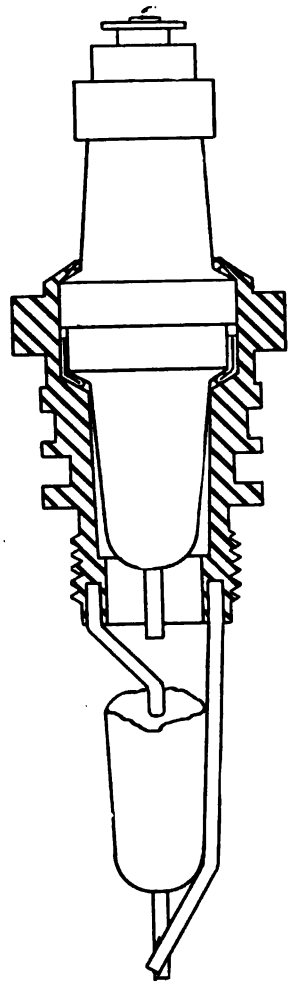

FIG. 10

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ature which is sufficient to cause preignition. Fig. 10 is another illustration of the same fact. In this case a section of a porcelain from a spark-plug is supported on wires extending into the cylinder. Again there is no preignition. Metal discs fitted on electrodes as shown in Figs. 11 and 12 cause no trouble.

The question now arises: How could there be continuous burning in the cylinder throughout the cycle without "popping back" in the carbureter? The explanation is that the rate of flame propagation is less than the velocity of the incoming charge, when the engine operates with the wide-open throttle at a speed of 1800 r.p.m., as in these tests. However, when preignition was present, if the engine was slowed down to 1400 r.p.m. "popping" in the carbureter would appear.

To prove definitely that preignition did produce this continuous burning, a window was constructed in the inlet manifold so that, with the inlet valve open, a portion of the interior of the cylinder could be observed. With a plug such as is shown in Fig. 4, a small section of the side electrode could be seen. When there was "popping" in the carbureter there would be a series of flashes visible through the window, but with the preignition at the speed of 1800 r.p.m. the observed phenomena were of continuous and rather gradual growth. Thus, with the engine operating normally everything would appear black; then the electrode would in turn become brighter and soon be surrounded by a small spot of reddish flame. As soon as the preignition trouble became pronounced, all of the cylinder that could be observed would appear to be filled with bright yellow flame. The special electrodes shown in Fig. 13 caused preignition and were of sufficient length that they could be easily observed through the window in the manifold. At about 1600 r.p.m. and 80 per cent full load the center electrode would be seen to glow. Under these conditions the engine would operate without trouble, but with a slight increase of load there would be a continuous flame around the electrode and all the evidences of preignition, namely, the long yellow flame, vibration, drop in power and excessive heat would appear. The plug shown in Fig. 14 gave no trouble itself, but when used in a cylinder in which the other plug was one that caused preignition, the nichrome wire, which melts at a temperature of 1500 deg. cent. (2732 deg. fahr.), fused. This is several hundred degrees higher than the average

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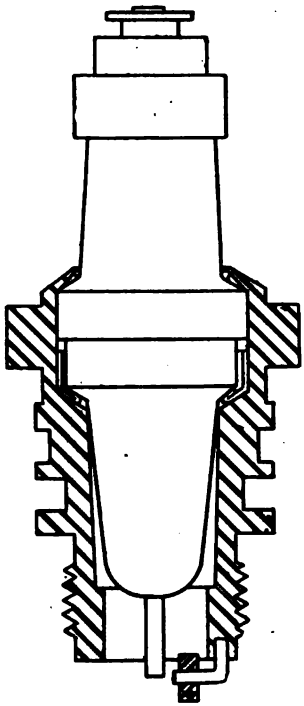

FIG. 11

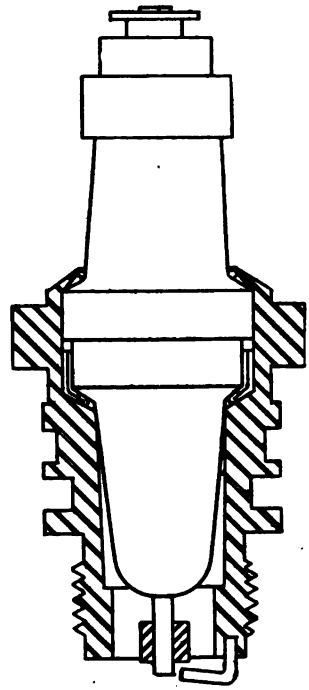

FIG. 12

temperature of a freely exposed wire in a cylinder under normal conditions.

Thus far these remarks have been confined to the "freak" plugs. The question now arises as to why the apparently normal plugs gave trouble. While most plugs that have given trouble have been found to leak around the center electrode, by no means all the plugs that leak here give trouble. Of twelve plugs known to have caused preignition, four were found to leak badly; while of the twelve that operated satisfactorily at the same time, none showed excessive leakage. While it seems reasonable that a leak should cause higher electrode temperatures, the leakage in the above mentioned four plugs seems as likely to have been the effect of the high temperatures, as that it was the cause of the preignition. There is a rather remote possibility that there exists sufficient difference in the heat conductivity of different porcelains to alter the electrode temperature enough to

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bring about these results. It seems plausible that in many cases the trouble is initiated not by the plug itself but by bits of incandescent carbon or other hot points within the cylinder. The design of the plug determines how long this can happen before the plug attains a sufficiently high temperature to continue the preignition temperature of its own accord. Another point that tends to show this is that some cylinders seem more prolific trouble-makers than others, and that often an adjustment of the mixture ratio away from that of maximum power will prevent the trouble; but once the trouble appears no adjustment will cure it.

Discussion of Results

These then are the outstanding features of this comparatively short series of tests. They serve as a means of identification of this form of preignition and as an indication of the abnormally high temperatures to which valves and combustion-chamber walls are subjected because of this trouble. Finally, they serve as a basis for predicting the performance of a given design of spark-plug or for designing a spark-plug to meet known conditions. Of chief importance in this regard is the fact that, to attain cooling of a spark-plug element, it is more effective to give free access to the cooling action of the incoming charge than to sacrifice this effect to protect the element from the hot explosive gases.

The contradictory demands made upon the spark-plug are realized. Electrodes must be run hot enough to burn clean and prevent fouling at light loads and at the same time be cool enough to prevent preignition at full load. A test similar to this suggests itself as a means for proportioning electrode sizes. It is to design the plug so that each electrode will just produce preignition trouble, at a compression ratio slightly higher than that with which the plug will be used. Care must be taken to avoid badly carbonized cylinders or anything other than the spark-plug that might cause preignition. It appears that in many cases the side electrode can be made smaller and still be less likely to produce preignition than the center electrode, or the latter could be made larger and still maintain a factor of safety against fouling greater than that of the side electrode. That, however, is the problem of makers and users of spark-plugs. It is as a supplement to their own experiments

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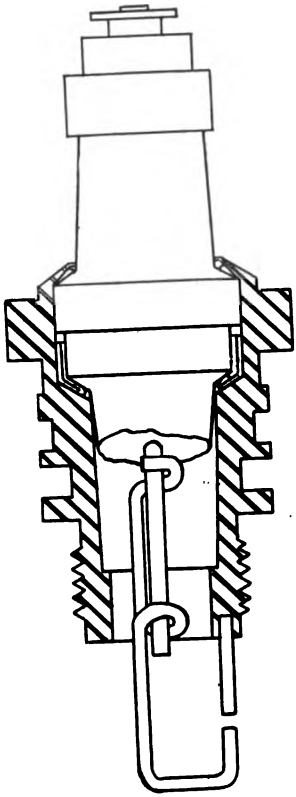

FIG. 13

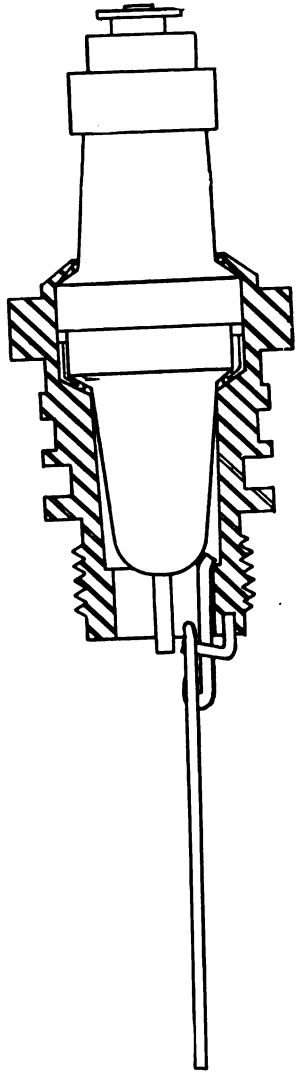

FIG. 14

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and as a suggestion for their further efforts that these results are presented.

THE DISCUSSION

THOMAS S. KEMBLE:—In 1915 the Curtiss VX engine was developed with a rather high compression-ratio for the sake of the advantages to be obtained at great altitudes. Inspection requirements, however, demanded full-throttle dynamometer tests of considerable duration and preignition developed. This was reduced to passable dimensions for dynamometer tests by reducing the compression somewhat and the air performance was very good for that period. Later, the volumetric efficiency was improved to such an extent that serious preignition again developed. This time repeated tests demonstrated that preignition occurred only in conjunction with leaky spark-plugs. The trouble was eliminated by using gas-tight plugs only. At that time gas-tight plugs were very difficult to obtain. Since then the situation has altered materially through the cooperation of spark-plug manufacturers and good plugs are easily obtainable. An interesting feature developed in that on at least three occasions a hole appeared in the aluminum intake manifold near one of the intake ports. This hole looked as if it had been caused by intense heat. We had been unable to get these engines to pop back through the carbureter intake without holding one of the intake valves well open. We therefore attempted to explain the manifold failure as being due to continuous popping back which failed to reach the carbureter intake. In view of Mr. Sparrow's observations through the intake manifold, I am convinced that our explanation was probably the correct one.

R. CHAUVEAU:—The tests we made during the war on various types of engines confirmed entirely the statements made by Mr. Sparrow. I will add an assumed explanation of the causes of the preignition. In the spark-plug shown in Fig. 2 it is, to my mind, due to the fact that there is an opening between what I would call the inner chamber of the spark-plug and the cylinder. The volume of this chamber is several times larger than the opening. During the explosion the pressure in the chamber is raised to the same degree as the pressure in the cylinder. This necessitates the passing of an amount of hot gases through the opening into the chamber. With these gases passing through a small opening alongside the electrode, it is natural to assume that they will trans-

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fer a certain amount of heat to the electrode itself, and this amount of heat is proportional to the speed and pressure of the gases.

The cooling of the center electrode is, in my opinion, effected mainly through the top of the electrode outside of the porcelain and only to a very small extent through incoming gases from the intake valve. That theory explains why we have preignition on the plug shown in Fig. 2 and not with the plug shown in Fig. 1, as the opening of the chamber is not restricted to any large extent. This theory was confirmed by another type of plug, of which I submit a sketch. As shown in Fig. 15, it

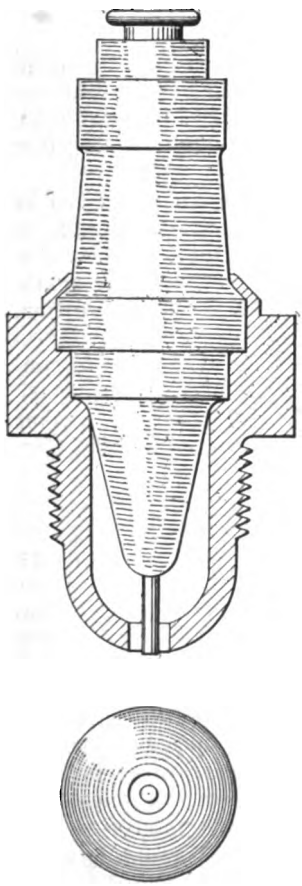

FIG. 15

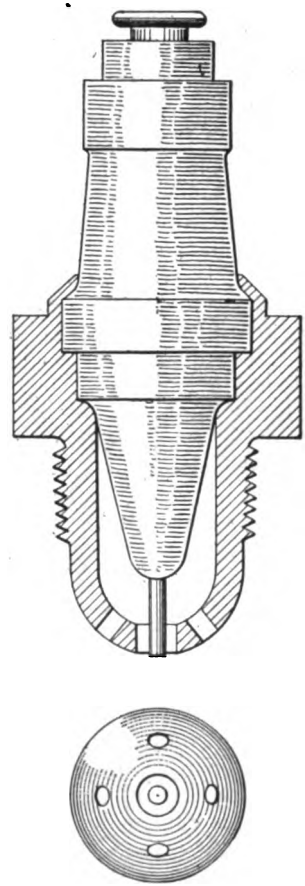

FIG. 16

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would consistently cause preignition. By drilling four holes, as shown in Fig. 16, in the shell, we would deflect a certain amount of the gases from the annular opening around the center electrode and eliminate the preignition. The plug shown in Fig. 3 in Mr. Sparrow's paper was claimed to cause preignition. This can be explained by the fact that while the opening is not restricted as much as in Fig. 2, at the same time the chamber in the shell has been increased 150 to 200 per cent, so that the proportion between these two remains about the same and, in addition, a larger area of the center electrode has been exposed. It is further proved in Figs. 5 and 6 that preignition is eliminated by increasing the opening to the chamber.

In conclusion, I would say that we have found the open-type plug the most satisfactory, and that the larger the center electrode is the less is the danger of preignition, provided the free end which extends beyond the porcelain inside the shell is short.

Another advantage in running the electrode as cool as possible, accomplished by the use of a heavy electrode, is the fact that it will cut down the leakage of the high-tension current and provide a more concentrated spark. The ground electrode is not likely to cause preignition, in conformity with Mr. Sparrow's statement. It is preferable always to use the single-ground electrode to concentrate the high-tension energy in one strong spark rather than distribute it among a number of weaker sparks. The single-ground electrode also cuts down electrical leakage.

In designing spark-plugs for aviation engines, I have found, however, that the engineer is limited as long as he has to use the materials now available for spark-plugs, and that it is impossible on this account to design one plug that will be universally good for all types of engines. In fact, a new engine and an older one of the same make, type and construction, require as a rule differently designed plugs, as the spark-plug in a new engine must be designed for high temperatures and a small amount of oil, whereas in an old engine the spark-plug must be designed for lower temperatures but for an excess of oil. It is only in rare cases that these two features can be combined into one spark-plug.

S. W. SPARROW:—Spark-plug leakage would be very apt to produce the preignition troubles described by Mr. Kemble. I think his explanation as to the cause of the

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hole in the intake manifold is undoubtedly correct. It is a pleasure to know that Mr. Chauveau's experience confirms so completely the results obtained in the tests at the Bureau of Standards. His explanation of the cause of the heating of the center electrode is of decided interest. I feel sure, however, that when an electrode is exposed to the incoming gases, much of its cooling is due to the heat taken from the electrode to vaporize the liquid fuel or oil that is thrown against it.

NEEDS IN ENGINE DESIGN

By F H Trego[1]

The author advocates the use of the fragile aluminum crankcase as a spacer, running crankshaft bearing bolts clear through the crankcase and the cylinder base, so tieing the bearings firmly to the cast-iron cylinder-block and using the through-bolts also as holding-down studs for the cylinders. The results of experiments on six-cylinder engines with reference to the satisfactory utilization of engine fuel now on the market are then presented. The problem is how to carry the fuel mixture in a proper gaseous state from the carbureter into the cylinder without having the fuel deposited out meanwhile. The power developed at engine speeds of 400 to 2800 r.p.m., with and without hot air applied to the carbureter, is tabulated, the proper location of the intake manifold is discussed, and the necessary features of a satisfactory engine to utilize present-day fuel are summarized.

I think it can safely be stated that present-day engine designing has as its principal problem that of devising ways and means for utilizing the quality of the fuel now on the market and with which the engine must operate in a satisfactory manner. Practically speaking, there is no choice as to the grade of fuel employed.

Through Crankshaft Bearing Bolts

The older engine designers have all had sufficient experience to avoid mistakes in laying out the engine and its various parts. However, from the experience we have had with aeronautic engines in the last four years, I think the supporting of the crankshaft bearings by hang-

[1] Vice-president and general manager, Trego Motors Corporation, New Haven, Conn.

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ing them from the aluminum crankcase is a thing of the past and that we should all follow the practice of running the crankshaft bearing bolts clear through the crankcase and the cylinder base, using them also as holding-down studs for the cylinders. The bolts should be in the form of large-size studs, threaded into the case at the lower end to prevent the crankshaft from falling down when the cylinders are removed. The effect of this method of support is to use the fragile aluminum case as a spacer and to tie the bearings firmly to the cast-iron cylinder-block, which is much stronger and stiffer for the purpose. The bearings are thus held firmly in line and because there is less spring in the support they wear much longer and the original clearance is thereby maintained.

Aside from this item I wish to devote this paper to the fuel problem and so will give the results of considerable experimenting with the six-cylinder engines that we have recently brought out. The fuel difficulty lies in our inability to supply a proper mixture to the cylinders at low speeds with full throttle or at moderate speeds and part throttle. I refer to engine speeds corresponding to car speeds of from 5 to 15 m.p.h. Condensation takes place in the intake passages on the way to the cylinders; the gas failing to arrive in proper condition and quantity to give even running on all cylinders in a multiple-cylinder engine, at least where there are more than four cylinders. The problem consists of carrying the mixture in a proper gaseous state from the carbureter into the cylinder without having the fuel deposited out on the way. To maintain the mixture in a gaseous state, some carbureter manufacturers call for hot air delivered to the carbureter intake; but if this is accomplished at a temperature sufficient to prevent condensation beyond the carbureter, the loss in power is prohibitive because of the decrease in volumetric efficiency. We find that at low engine speeds the condensation seems to be aggravated to some extent, under certain conditions of road travel. For example, take a three-passenger car, weighing 3300 lb. and having a gear ratio of 4 to 1 and 33-in. wheels, equipped with our own engine, which is an L-head type with a 3½-in. bore, 5-in. stroke and a 1¼-in. carbureter. Such a car will, when starting at 20 m.p.h., go over the top of a grade rising 500 ft. in ¾-mile at a speed of 25 m.p.h. without feeding hot air into the carbureter; while by making no change other than adding hot air we are just able to

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get over the top at about 8 m.p.h. On maximum speed tests over a level concrete road we obtain 65 m.p.h. without hot air and 55 m.p.h. with it.

Application of Hot Air to Carbureter

It should thus be evident that taking hot air into the carbureter intake to overcome condensation is not good practice and some other means must be found to prevent condensation in the intake passages. Where it is impossible, without too much change in the design, to apply heat between the carbureter and its cylinders, a change in the valve-timing will assist greatly. In this case the intake valve on a six-cylinder engine should be closed 15 deg. after bottom center and not at 30 deg., as is the usual practice. In 1913 I found this to be of great benefit in the case of Packard engines, which "loaded" badly on hills at low speed with wide-open throttle. The change in valve-timing eliminated the condensation at that time, and did not affect the maximum speed. We were still able to run 72 m.p.h. with the model 48. The early timing is beyond the experimental stage and has become standard practice on all our six-cylinder models.

This timing is not sufficient to prevent the condensation of the grades of fuel which are now generally sold; to obtain adequate performance we are now obliged to apply heat to the mixture after it leaves the carbureter.

The following table gives the power with and without hot air, other conditions being the same. The figures are averages of three runs each on an electric dynamometer.

Engine Speed, r.p.m.	Power Developed with Hot Air, hp.	Power Developed without Hot Air, hp.
400	9.3	12.1
600	13.2	18.7
800	19.7	25.6
1,000	26.1	32.7
1,200	32.2	38.6
1,400	39.4	44.8
1,600	46.8	50.0
1,800	51.3	55.3
2,000	55.0	58.5
2,200	55.5	61.0
2,400	54.0	57.6
2,600	52.0	56.5
2,800	46.9	55.3

The low speeds would have been even worse with hot air, if they had been maintained for some time, as in the

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case of climbing a long grade, but the figures shown are probably the same as on the road for high speeds.

With the 15-deg. late closing of the intake valve, this six-cylinder engine performed satisfactorily on the road until cold weather came on, but we then found that the engine would jerk badly when running at 10 m.p.h. with throttle cracked and "load" to a considerable extent on a long slow pull with a full throttle.

Location of Intake Manifold

The entire intake manifold of the engine lies within the water-jacket from which insufficient heat is absorbed to prevent the missing of the cylinders farthest from the carbureter. Where the exhaust ports pass over the intake manifold "hot spots" are formed; but the heat from these proved insufficient for the purpose and a final change was made whereby the exhaust manifold was disposed alongside of the intake manifold for its full length. The result was that the jerking or missing entirely disappeared and the car performance on the road was much more lively, with better acceleration, hill-climbing and low-speed work down to 1 m.p.h., with a loss of only 4 hp., due to decreased volumetric efficiency. This small sacrifice was more than compensated for by the better general performance.

Another important effect of the heat addition was noted in the good performance of the car with a cold engine and without the use of a choke on the carbureter intake or other device to enrich the gas mixture. Thus smoking and other detrimental effects of running a cold engine with a rich mixture were avoided. In completing the experiments, we found that best all-round performance was obtained by admitting just enough hot air to the carbureter to warm it slightly.

Care should by all means be taken to avoid any down grade in the gas passages after they leave the carbureter, for condensation is sure to take place with low vacuum unless a very high degree of heat is applied. This is, no doubt, the reason that in some V-engines raw gasoline goes into the crankcase past the pistons, for as soon as the throttle is opened the raw deposited gasoline runs into the cylinders instead of being drained back to the carbureter.

Careful experimenting should be carried on with each new engine to insure that the intake passages are as small as possible without the loss of too much power at

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the higher speeds, for if they are made of a size large enough to give maximum power at high speed they will, under average running conditions, call for the application of much heat to the mixture after it leaves the carbureter. On the six-cylinder engine above mentioned we found that a minimum diameter of 1⅜ in. was required for the cored passages, which were naturally more or less rough on the inside. The compression space is 23.2 per cent of the total volume.

To sum up, the necessary features of a satisfactory engine with present-day fuel are

(1) Closing the intake valve early

(2) Small size of intake passages

(3) Application of heat to the mixture after it leaves the carbureter

THE DISCUSSION

THOMAS S. KEMBLE:—I am constrained to take exception to Mr. Trego's deductions regarding the practice of running crankshaft bearing bolts clear through the crankcase and cylinder base and using them as holding-down studs for the cylinders. This practice may serve to reinforce a fragile crankcase, but it often causes distortion and is not at all necessary in connection with a properly designed crankcase. If the aluminum crankcase is extended to form the water-jackets as in some of the best aviation engine designs, through-bolts are out of the question. In four years' experience with high-duty aviation engines where through-bolts were not used, I have not observed a single instance in which the crankshaft bearings were adversely affected. Some of the earlier engines with individual cylinders developed trouble in the crankcase deck due to lack of rigidity, but this was completely remedied by the addition of very light inexpensive ribbing.

In the matter of heat application to improve distribution and smooth running, we are still unable to avoid some reduction of volumetric efficiency. Exhaust heat properly applied has decided advantages over the old-style water-jacket and hot-air intake. Improved operation with early closing intake valves can be ascribed to the elimination of "blow back" into the manifold at low speeds.

Mr. Trego's summing up certainly is another indica-

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tion of the general situation that we are unable to avoid reduction of volumetric efficiency. Progress along this line has not kept pace with requirements and perfection is not yet in sight.

H. C. GIBSON:—The attention Mr. Trego has called to the advantage of through-bolts, tieing the crankshaft bearings to the cylinders, is particularly interesting. I am sure that for all classes of engine the chiefs of production departments will find great advantage and will readily cooperate with engineers in the general introduction of this direct method of resisting those major engine strains through dependable economical steel rods, thus placing castings, which are always of uncertain dependability, under compression only. It is a comfortable thought of proved value in practice, and should be carried to the extent of holding down removable cylinder-heads by the same bolts.

Mr. Trego's paper and mine are surprisingly opposed in the analyses of engine needs regarding fuel; hence I must suggest some reasons for the astonishing results of tests he gives and for one of his recommendations which appears undesirable. Taking the statement of the test of the three-passenger car, I note that its speed was reduced from 25 to 8 m.p.h. over the hill-top when hot air was fed to the carburter, no other change of condition having been made. I suggest that if the carbureter were adjustable and had been adjusted coincidently with the application of hot air, an economy of gasoline and at least equivalent speed would have resulted. It is worse than useless to turn on hot air to a carbureter set for cold air, because the heat vaporizes more of the fuel, enriching the mixture far beyond the proportion which will give maximum power. This seems to have happened in the case Mr. Trego has cited. There is no other reason for the results, which are contrary to my experience. Even excessive temperature of the air could not be blamed if adjustment were neglected. Will the author please state the temperature used?

Mr. Trego is evidently strongly in favor of "volumetric efficiency per stroke." Granting that hot air or manifold mixture heaters do reduce such efficiency somewhat, I fail to grasp the value of further reduction by adopting his recommendations of small sizes of intake passages. Logic seems to indicate that, having caused vaporization through heat, we do not need the high speeds of intake gases which were universally used in

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the trade prior to the date when makers, finding such methods ineffective, undertook to add at least some heat to intake gases. Small intake passages cause loss of volumetric efficiency; they are unnecessary and detrimental when the gases are properly heated.

The inlet manifold being entirely water-jacketed, as Mr. Trego states, no doubt causes the peculiar happenings recorded. My company has lately developed the fact that 5 cc. of the lower-boiling-point fraction of a common engine gasoline, held at 180 deg. fahr., required 5 min. for complete evaporation; while 5 cc. of the higher fraction required 6 hr. It is clear from this that water-jacketed inlet manifolds should be avoided. Such jacketing will nullify or offset any effort made to evaporate gasoline prior to entering the manifold, and will destroy the value of test records of heating methods.

Mr. Trego brings out a valuable point in recommending earlier closing of the inlet port when using heat. Later closing was necessary to take advantage of the cylinder-filling ability of a column of gases traveling at high velocity; with decreased velocity earlier closing is an advantage. The application of heat to the mixture after it leaves the carbureter is a correct recommendation. I would add that it is also of advantage to use heated air of constant temperature.

F. H. TREGO:—I appreciate that running the crankshaft bearing bolts clear through is impractical when using the water-jackets and crankcase in one piece; but this makes a very unhandy piece in the manufacture of commercial engines, and my paper does not refer to the design of aeronautic engines.

The principal effect of the long bolts for the bearings is shown in the slight wear of the bearings as against the wear when the bearings are held in the crankcase only, and of course the wear will be less if the crankcase is heavy and heavily ribbed; but we are all anxious to get light weight in our passenger-car engines and the running through of the bearing bolts allows a very light crankcase, at the same time assuring rigidity and long wear on the bearings. No distortion can take place through the use of the bolts if the vertical ribs at each bearing boss are extended to the end of this boss, for then the boss with its ribs becomes a simple spacer and should withstand the crushing strain of the bolts. Running 100 hr. with a dynamometer, at speeds from 1000 to 3000 r.p.m. while making power curves, developed no

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bearing wear; and this should be equal to about 40,000 miles at 40 m.p.h.

The application of heat after leaving the carbureter, even to the extent to which we have carried it, loses but 4 hp. on the dynamometer at 2600 r.p.m, but on the road the car was even faster than before and the acceleration was much improved, so that although a slight loss of 6 per cent was indicated on the test stand it did not show up on the road.

I object to holding down the cylinder-heads with the crankshaft bearing bolts, on account of their extreme length if used for this purpose. The stretching of the bolts, unless they are very heavy, would be the objection to this practice.

On the speed and hill-climbing tests made with and without hot air in the carbureter, we adjusted the carbureter in each case for maximum speed and acceleration, so I deduced that the lack of heat after leaving the carbureter allowed condensation in the intake passages between there and the cylinders, thus causing the loading which of course killed the pulling ability of the engine on the grade.

Regarding the size of intake passages, we experimented with 1½, 1-7/16, 1⅜ and 1¼-in. sizes, finding that the 1⅜-in. size gave the best all-around results and did not fall below 65 hp. on the 3½ by 5-in., 6-cylinder, L-head-type engine. Mr. Gibson may not call 1⅜ in. "small," and therein would lie his disagreement with me on this matter, but our object was to keep the velocity as high as possible without decreasing volumetric efficiency.

I agree with Mr. Gibson in the statement that we would not need small intake passages if the gases were properly heated; but thus far I have been unable to obtain sufficient heat to reach such a condition. Our engines run exceptionally cool, but we find a jerking at about 10 m.p.h. with light throttle, unless the heat is applied, and even though the entire manifold, if at least as small as 1⅜ in., is within the water-jacket except along one side, which is exposed to the exhaust gases.

The early closing of the intake valve is only recommended in six-cylinder engines when one carbureter is used. Closing the intake much later than 15 deg. is perfectly practical on a four-cylinder engine, or on a six-cylinder engine if a carbureter is used for each three of the cylinders, where there was no overlapping

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of the suction stroke that would interfere with the filling of the cylinders.

Referring to the size of intake passages, if the spark-plug is placed in such a position that the flame propagation has an equal distance to travel in all directions, the compression can be carried higher and we thus get the stronger suction which will pass the required amount of gas even though the intake passage is small. The compression of 23.2 per cent of the total volume is carried on both the L-head and the I-head engines; no hammering takes place in the L-head engines, such as would be the case if the spark-plug were carried over one of the valves. I would therefore recommend the use of high compression, proper location of the spark-plug, smaller intake passages and the application of all possible heat after leaving the carbureter.

ADAPTING ENGINES TO THE USE OF AVAILABLE FUELS

By J G Vincent[1]

Some of the salient facts regarding the character of the engine fuel marketed within the past few years are shown in accompanying curves. The desirability of operating present-day experimental cars with fuel that is the equivalent of fuel that will probably be generally marketed two years hence is stated and various methods of meeting the fuel problem are then examined. A dry fuel mixture is desired to prevent spark-plug fouling, to improve engine performance in cold weather and to minimize lubricating oil contamination by fuel which passes the pistons. Various methods of obtaining a dry mixture are then discussed, leading to a detailed description of the construction and operation of a device specially designed to accomplish such a result more successfully. In principle, this takes advantage of the difference in pressure existing on either side of the carbureter butterfly-valve and causes a small amount of the combustible mixture to pass through a passage parallel with the main carbureter passage. This mixture is then burned in a suitable burner and the burnt gases allowed to mix with the incoming main supply to the engine above the throttle. This gives maximum efficiency under low throttle and light load

[1]Vice-president in charge of engineering, Packard Motor Car Co., Detroit.

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conditions. When high volumetric efficiency of the engine is desired under wide-open throttle conditions, very little mixture passes through this shunt passage and a negligible amount of heat is produced in the burner.

Probably the most absorbing topic today in the automotive engineering world is the fuel question. This is as it should be, for it is essential that we design engines which will utilize not only the fuel that is being sold today but also the fuel which will be on the market two or more years hence. There has hitherto been an entire lack of cooperation between the men who determine what kind of fuel is to be marketed and the engineers who design the car to use this fuel. This is obviously wrong. It is time that we devise some system which will insure the realization of the entire useful life of the cars we are designing today, rather than have them discarded or run under adverse conditions when the quality of the fuel deteriorates. Furthermore, we must recognize that the character of the fuel must change if the automotive industry is to expand in the future as it has in the past. The petroleum resources of the country are already taxed to the limit to supply sufficient gasoline for the cars now in use, and the only apparent way in which this fuel supply can be materially increased is by utilizing some of the heavier fractions which at the present time are not considered fit for automotive use, or possibly by an extension of the various cracking processes, some of which have shown considerable promise.

The accompanying curves are intended to bring out some of the salient facts in regard to the character of the fuel marketed in the past few years. Of course, there is no one quality in a fuel that can be considered by itself as controlling its suitability for automotive use. Only three characteristics which are of special interest have therefore been plotted, although many additional considerations are to be borne in mind. It will be noted that the end-point of the average gasoline has been rapidly ascending in the last four years and is now but little less than the end-point of the kerosene of today. The gravity, Baumé, readings are slowly descending but the initial boiling point has not undergone much change. As long as this latter condition holds we shall not have much trouble in starting engines in cold weather, but the use of a tight-fitting choke will become more and more of a factor in determining how quickly the engine will fire,

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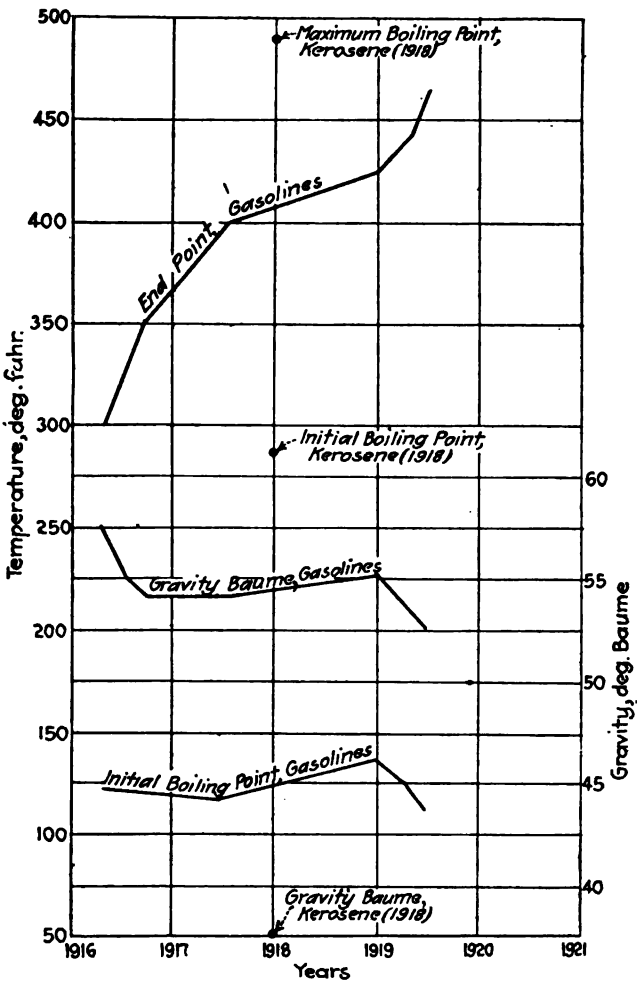
since at low temperature we can volatilize only the lighter constituents of the fuel, and as the percentage of these lighter constituents in relation to the whole goes down, we must get a larger amount of gasoline into the cylinders to have enough of the lighter constituents to start combustion.

A point I would like to impress upon you is the desirability of having our experimental cars running today



VARIATIONS IN GASOLINE FROM 1916 TO 1919, INCLUSIVE, BASED ON DATA OBTAINED FROM GASOLINE PURCHASED IN CARLOADS

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on a fuel that will be the equivalent of fuel to be generally marketed two years hence. Thus far lack of cooperation between the fuel producers and refiners and the automotive industry has prevented a forecast of fuel characteristics such as to enable car designers to design engines to handle properly the fuel available.

Meeting the Fuel Problem

Let us now examine various methods of meeting the fuel problem. There was a time when we pointed with pride to the frost on a bare aluminum intake header, considering this a very desirable symptom indicating perfect vaporization. This applied when we were dealing with fuels of about 80 deg., Baumé, which vaporized under the conditions obtaining in the manifold at ordinary temperatures. The low temperatures produced by this vaporization increased the volumetric efficiency of engines very materially and cold headers were therefore looked on with favor. Thus we have repeatedly demonstrated on Liberty engines that 500 hp. or more can be developed by one of these engines, which normally will give about 420 hp., by using high-test gasoline and getting the mixture into the cylinders cold enough. But nowadays we are dealing with fuels which refuse to vaporize at ordinary temperatures in the header. In the course of some experiments with glass manifolds I found that when using 56-deg. Baumé gasoline it is necessary to put the mixture into the cylinders at about 180 deg. fahr. to secure a perfectly dry mixture. Of course, this is going to the extreme, and for all practical purposes the mixture can be somewhat wet and yet the engine will function properly. We will therefore assume that a mixture temperature of 120 deg. fahr. is the minimum to be used.

I would like to state some of the reasons why the mixture should be introduced in as dry a condition as possible. From the standpoint of the driver the item first in importance is that of spark-plug fouling. Repeated experiments have shown that such fouling in the great majority of cases is not due to over-oiling, as commonly supposed, but to the presence of wet fuel on the plug, which, in connection with the small amount of carbon that is formed on the porcelain, apparently has the property of making the surface a sufficiently good conductor to enable the high-tension current to leak over

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the surface of the porcelain rather than jump the gap. Clean oil is a good insulator, and when a plug does not fire because of oil, this is due to the fact that the oil acts as an insulating material between the electrodes. If the mixture is introduced into the cylinders in a dry state and does not condense afterward, it is obvious that no wet fuel will appear on the porcelain. Practical experience of many months on several cars has shown that this is the secret of preventing spark-plug fouling.

Second in importance to the driver is the question of performance with a cold engine. I believe that we have all had the experience of trying to drive a car in excessively cold weather with the engine sputtering and coughing so that we could hardly get into high gear. During the past few years we have used thermostats, water-jacketed headers, hot-spots and heated air intakes. All these, of course, help the situation somewhat, but I believe that with the fuel getting worse more rapidly than the engine is improving the winter operation of cars is becoming less satisfactory each year.

The third item in order of importance, insofar as the owner is concerned, is the contamination of the lubricating oil by fuel which passes the pistons. This is a serious problem, for few owners will go to the trouble of draining off the oil at compartively short intervals in winter. In consequence the lubricating system soon becomes filled with a mixture of fuel and oil of little or no lubricating value.

There are many minor questions involved when we try to distribute and burn a wet mixture. Many have tried numerous types of intake headers to find which insures the nearest approach to equally proportioning the air and gasoline to each of the various cylinders. We are often using gas velocities in the intake header exceeding 100 m.p.h. and it is therefore to be expected that the liquid gasoline will separate from the air stream, due to its greater inertia. Of course, when the gasoline is turned into a dry gas it behaves just like air and takes the turns nicely along with the air. The failure to obtain prompt response when opening the throttle quickly when using a wet mixture is also undoubtedly due to the fact that the air will accelerate more quickly than the liquid gasoline particles, with the result that the engine either "lies down" or spits back. When a dry mixture is used we can step on the throttle and get instant response. The more finely divided the gaso-

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line, the better the engine responds. It is conceivable that a finely atomized mixture of liquid gasoline and air can be made to perform as well as a dry mixture, but it is one thing to produce a finely atomized spray of gasoline and another to maintain the gasoline mist in this condition until it is fired.

Securing a Dry Fuel Mixture

I take it that we are now all agreed that a dry mixture is desired. There remain to be examined the various methods of obtaining this result. The commonest one now employed is to utilize some of the heat contained in the exhaust gases, and since there is expelled in the exhaust from 20 to 40 per cent of the heat units contained in the original gasoline, depending upon the engine speed and other considerations, it would appear that this is the most practical and economical way to obtain the result. Theoretically it undoubtedly is, but practically, in some cases, the method presents serious objections. If we assume that the intake and exhaust manifolds are in some manner constructed integrally, it is obvious that the temperature of the intake walls will vary in proportion to that of the exhaust walls. This, of course, means that at high speed and under heavy load the walls will be very much hotter than at low speeds and light loads. It is therefore obvious that if the intake header is sufficiently hot to do the job at low speeds and light loads, it will be altogether too hot at high speeds and heavy loads to obtain the maximum volumetric efficiency of the engine. Of course, there are many cases where a high volumetric efficiency under heavy loads or at high speeds is not essential, so that this solution gives pretty fair results. We are all, however, striving to get the most power possible out of the least engine, and it certainly hurts to cut 10 or 20 per cent off the maximum output of the engine to insure a dry mixture at low throttle and light loads.

Then again there are various compromise schemes most of which are based on the theory that it is possible to locate a very hot spot at such a point that the heavy particles of the fuel will be thrown against this surface and vaporized, whereas the air and the lighter particles will be diverted from the hot-spot by the particular design of the header. This would be fine if it were possible to get the hot-spot hot enough under low throttle conditions. It is undoubtedly a good compromise scheme

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and does not detract from the volumetric efficiency of the engine to the extent that the regular exhaust-jacketed job does.

We now come to electrical means of supplying the heat necessary for vaporization. To illustrate the impracticability of this solution let us make a few assumptions which will represent a hypothetical case. What we want to find out is how much heat it is necessary to supply to a header to insure a reasonably dry mixture under average driving conditions. Assume an hourly gasoline consumption of about 2 gal. or about 12½ lb. Assume that this gasoline is of 56-deg. Baumé gravity and that its latent heat of vaporization is 150 B.t.u. per lb., this figure varying according to different authorities, and the pressure under which vaporization takes place but being sufficiently accurate for our purpose. Assume an air temperature of 40 deg. fahr. and that it is necessary to put the mixture into the cylinders at 120 deg. fahr., which is far from being a dry mixture, but experience has shown that this is sufficiently dry to eliminate most of the troubles which I have enumerated. Assume also a rather rich mixture, say about 13 to 1; this will give us about 162 lb. of air to combine with the 12½ lb. of gasoline. The specific heat of air is 0.1689 and of gasoline 0.51, so that to raise the gasoline and air from 40 to 120 deg. fahr. and completely vaporize the fuel requires:

	B.t.u.
Latent heat of 12½ lb. of gasoline	1,875
Heat to raise 162 lb. of air 80 deg. fahr	2,189
Heat to raise gasoline 80 deg. fahr	510
Total	4,574

To supply 4574 B.t.u. per hr. electrically is equivalent to the consumption of about 1.34 kw. per hr. which in turn would be represented by a current consumption of 223 amp. at 6 volts. These calculations of current consumption, of course, assume 100 per cent efficiency on the part of the electrical heating system which, obviously, it would be impossible to attain. It will therefore be seen that the electrical solution does not appear very promising in view of the high current required. It is also evident that this heat cannot be supplied to the intake header by the circulating water unless a header be designed with a great deal of radiating surface in contact with the water, and even this would give very slow

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heating-up conditions although a thermostat were employed.

Another Solution of the Problem

It was these various considerations that led me to look elsewhere for a solution of the problem. It appeared desirable to evolve some simple inherently automatic method of supplying the heat, not possessing any of the disadvantages cited above. It was shown that about 4574 B.t.u. per hr. would represent an average requirement. Assuming that there are 19,000 B.t.u. in 1 lb. of gasoline, it will be seen that we could secure the necessary heat from the complete combustion of 0.24 lb. of gasoline per hr., providing we could attain a 100 per cent heat transfer. We do not, of course, obtain 100 per cent efficiency with the scheme I am going to describe, but I believe that from a thermal standpoint you will agree that it is a very efficient arrangement or one representing really small heat losses. The principle of this device is to take advantage of the difference in pressure existing on either side of the carbureter butterfly-valve and cause a small amount of the combustible mixture to pass through a passage which is in parallel with the main carbureter passage, burn this mixture in a suitable burner and then allow the burnt gases to mix with the incoming main supply to the engine above the throttle. It was evident immediately that this general scheme would be at its maximum efficiency under low throttle and light-load conditions; an intense heat is generated very promptly under these conditions, which are obtained when starting up and idling. On the other hand, under wide-open throttle conditions, when we wish to maintain the volumetric efficiency of the engine as high as possible, but very little mixture passes through this "shunt" passage and a negligible amount of heat is produced in the burner. Of course, the reason that the mixture need not be heated for wide-open throttle conditions is that combustion is largely assisted by the increased turbulence, increased compression pressures and naturally higher jacket-water temperature.

There are four main units which combine to give the desired result. They are briefly as follows:

(1) A special inlet manifold which has a water-jacket as well as a combustion jacket
(2) A burner which is attached to the combustion jacket

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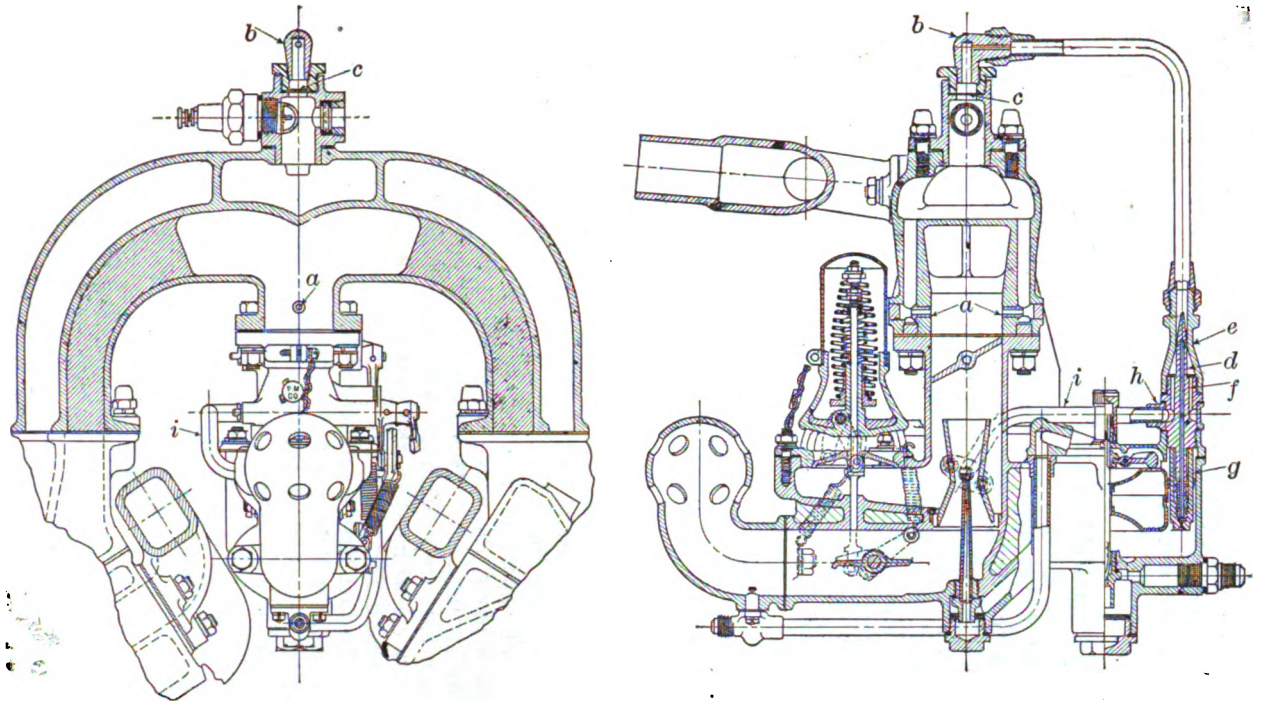

ELEVATIONS, PARTLY IN SECTION, OF A MANIFOLD DEVELOPED TO SOLVE THE FUEL PROBLEM

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(3) A vaporizer or miniature carbureter which is used to furnish the mixture for the burner

(4) An auxiliary ignition breaker and coil which is used to furnish the spark for the burner spark-plug

The manifold as shown on the accompanying drawing is of the conventional construction except for the additional jacket used for the hot gas which communicates with the main intake passage through the two hollow "suction" plugs shown at *a*. The burnt gas joins the main mixture after coming through these holes and the proportions are such that at no time does the burnt gas come into contact with the new mixture at a sufficiently high temperature to preignite the mixture.

The burner body is fastened to the manifold by the two-bolt flange shown, and in the burner body there is formed a combustion chamber into which a spark-plug fitted with a wide gap is inserted, as well as an observation window of heat-resisting glass which permits the action of the burner to be observed at all times. The mixture from the vaporizer is supplied by a ⅜-in. copper pipe and enters the combustion chamber after passing through a calibrated hole in the elbow shown at *b* on top of the burner and a screen *c*. The purpose of the latter is to assist in the atomization and even distribution of the incoming mixture. The mixture is supplied by the vaporizer shown at *d*, which is composed of four main parts, the choke *e*, the jet *f*, the jet sleeve *g* and the air intake *h*. This vaporizer is intended to function as a carbureter through a limited range of depressions. It is constructed on the general principles embodied in several different types of plain-tube carbureters and relies on the fact that a submerged jet exposed to atmospheric pressure will feed a fixed quantity of fuel, and that by suitable control of the depression over this jet the flow of fuel can be accelerated in just the degree required for an increasing suction and supply of air. Accordingly the level of gasoline in the sleeve *g* rises and falls as the suction in the venturi *e* decreases or increases. Control of the mixture supplied by this miniature carbureter to meet various temperature changes and starting conditions is attained by the simple means of coupling the air intake *h* to a pipe *i* which takes its air from the auxiliary air supply of the carbureter, as shown.

In connection with the air-valve type of carbureter around which this device has been designed there is a

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dash adjustment that permits the driver to control the depression existing in the auxiliary air supply passage so that when starting out on a cold day both the main and the auxiliary carbureters can be made to supply a richer mixture simultaneously by means of the dash adjustment.

The high-tension current for the burner spark-plug is supplied by an independent ignition coil, the primary circuit of which is wired in parallel with the regular ignition circuit; the extra coil is controlled by a separate contact-breaker. The latter is operated by the same cam as the regular engine ignition contact-breaker. It will thus be seen that the burner spark-plug is operating whenever the engine ignition is operating, and in the case of the twelve-cylinder engine there are three sparks in the burner per revolution of the engine. I have not found it advisable to cut off this spark or control it in any way, since except for the small amount of current used by the extra coil there appears to be no disadvantage in allowing it to operate continuously.

How the Device Operates

In actual operation, when the engine is idling, combustion takes place in the burner silently and continuously and a bluish-green flame completely fills the combustion chamber. This flame diminishes in intensity as the throttle is opened and the depression in the main intake header is thereby decreased, the general result being that for ordinary driving conditions up to 25 m.p.h. a mixture temperature of 150 to 180 deg. fahr. is maintained, giving perfect distribution, excellent acceleration, absence of spark-plug fouling and elimination of dilution of the lubricant in the crankcase. At higher speeds and wider throttle opening the influence of the combustion heater gradually decreases until at wide-open throttle it is practically out of action, which is exactly the condition desired. This combination has permitted the running of a twelve-cylinder engine on kerosene at moderate driving speeds with practically the same results as when using gasoline, but when using kerosene there are critical temperatures below which we cannot go without considerable spark knock. The problem of burning kerosene is, of course, something that we do not yet face, but the design of this heater can be modified to permit any shape of temperature-load curve desired. The combustion heater as at present constructed does not permit us to start on

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kerosene, but simple modifications would permit this to be accomplished.

One question that naturally arises is: What effect has the combustion heater on gasoline economy? I have conducted a great many experiments in an endeavor to answer this question. A series of tests was made on the dynamometer, the results of which are shown in the accompanying table. In these tests the gasoline consumption of the engine and of the burner were measured separately. It will be noted that the consumption of the burner, when idling, was 0.066 gal. per hr. This is slightly over ½ pint per hr. It will also be noted that under

GASOLINE CONSUMPTION OF A 3 BY 5-IN. TWELVE-CYLINDER ENGINE USING COMBUSTION HEATER

Engine Speed, r.p.m.	Equivalent Car Speed, m.p.h.	Brake Horsepower	Gas Consumption, gal. per hr.		Burner Consumption / Engine Consumption	Temperature of Manifold, deg. fahr.
			Engine	Burner		
350	Idle	.....	1.02	0.066	0.064	218
400*	9.5	2.33	1.32	0.054	0.041	210
800*	19.1	5.07	1.80	0.054	0.030	200
1,200*	28.6	10.00	2.40	0.066	0.027	187
1,600*	38.2	16.53	3.30	0.114	0.035	156
1,600	38.2	32.00	4.27	0.102	0.024	150
1,600	38.2	63.00	7.20	0.060	0.008	146

*Assumed average driving conditions.

average driving conditions the engine fitted with a combustion heater may consume approximately 3 per cent more than one without the heater, but it is possible to save a considerable amount of gasoline under such driving conditions as call for frequent accelerating, owing to the improved performance obtained with a dry mixture. In cold weather and even in hot weather it is possible to run with a much leaner mixture when the mixture is dry, and this will more than offset the slight amount of gasoline which the burner uses. I believe that taking an average over city and country mileage there will be little, if any, difference in the matter of gasoline consumption in moderate weather between a car fitted

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with a combustion heater and one not so equipped, but that there will be a noteworthy saving in cold weather.

In conclusion, I would say that it has been demonstrated that, in addition to its other advantages, this device will appeal to both the careless driver who omits to change the engine oil frequently in winter and the careful driver who has hitherto taken this necessary precaution. In the first case it will serve to prevent damage to the engine, which is the result of the poor lubricating qualities of a mixture of fuel and oil, and in the second case it will materially reduce cost of operation.

THE DISCUSSION

H. M. CRANE:—My first impression was that we had here another cylinder added to a crankcase that was already somewhat overcrowded. That is not entirely a humorous conception. The necessity for devices of this kind is a function of how good the inlet manifold itself may be, combined with the carbureter or vaporizer. Our experience through a great many years has indicated that an inlet manifold which does not continue in an upward course practically the whole way from the carbureter to the cylinders is a far more difficult proposition to handle than one in which such a condition holds. The reason is quite plain; we have the effect of gravity working on the heavy fuel, which is almost always present as a liquid in the mixture, in addition to the effect of the air-stream. If we have a sufficient air-stream to carry the liquid fuel, the distribution is relatively easy. The minute the air-stream falls to such a slow speed that other elements enter, the distribution is almost impossible, but by getting an ascent of the mixture from the carbureter to the engine the gravity interferes less with the air-stream.

On the other hand, I think that the device described is a very interesting example of the conception that the way to warm up an engine is to use a little fuel especially for that purpose, rather than to use the whole engine itself as a heater. I think that there is no question that we can get the results far more economically in the way that is shown in the paper, than we possibly can by any system which involves operating the engine until various parts of it become warm enough to do the work. The only thing that is apt to be complicated by a device of this kind is the idling condition of the engine. We all know that to idle an engine properly, where the inlet manifold will show nearly 20 in. depression of mer-

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cury, the slightest leak in any place is almost certain to upset the conditions, and here we have a continuous leak of burnt gas into the manifold, practically past the throttle, which is certain to make the idling situation more difficult than it already is. It is possible, of course, that the addition of the extra heat will tend to overcome the conditions raised by the very heavy fuels which do not vaporize well at the slower speed, i.e., the air speed, that obtains under idling conditions. There is no question either, from the layout of this drawing, that the device has been very carefully worked out and applied in a way that is probably about as near correct as is possible on this particular job.

R. W. A. BREWER:—In one part of his paper Mr. Vincent says that he wants to get 100 per cent of heat transference from the heating means to the fuel and air-stream. I rather wonder why he did not burn the fuel inside the air-stream instead of outside. That has been done in many cases. I recall the work that was done by the Commercial Cars, Ltd., of London, for example, about 1913, where a very crude attempt was made to provide that previous high temperature zone which is so desirable and so necessary in any system which we must adopt at the present time, working along Mr. Vincent's lines.

There are two ways of investigating this problem. One is the way propounded, in which we have a sufficient zone of high temperature, which should not for a moment be confused with the question of quantities of heat. The second is to treat the fuel and air mixture so that liquid does not pass through into the engine cylinders. What we are aiming at, in order to obtain the best results, is a dry mixture in the engine cylinders. If that is accomplished, a great many of our problems disappear. To obtain this dry mixture, Mr. Vincent has resorted to the locally-heated system. We must bear in mind that local heating is a question of supplying at the right place a metallic surface, if need be, upon which certain fractions of the fuel, and those only, can impinge. He rather decries the work of others in that field, when he states that certain attempts have been made by design, etc., to localize these areas of high temperature with a view to attaining a certain end. I believe these areas can be localized, and I believe that the design of the pipe can be such that the desired end is attained. It seems not to be so fully understood as it should be, that fuel in suspension in an air-stream does not lie homogeneously through-

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out the air-stream. The previous speaker referred to the question of carrying liquid in suspension at a sufficiently high velocity. If we could do that everything would be well, assuming, apparently, that the liquid particles were distributed in a homogeneous mass throughout the stream, which of course we know is not the case.

An important point in connection with manifolds of this type, when we can obtain a dry mixture, is that the effect of valve-timing is not at all serious. We have seen great research into variations of valve-timing and one often notices on drawings the valve-timing specified to degrees and fractions of a degree. I think it is rather straining a point when the system is pursued to that very great degree of fineness, because the effect of the intake manifold is very much greater than the effect of any sort of valve-timing, or a great many other problems such as valve areas, which have been foremost in automobile thought for some time. For example, the effect of turbulence is very important and should be considered most carefully in the design of an engine. We have previously had a little sidelight thrown on this question of turbulence, and it should be borne in mind very strongly by men who are considering the whole of this problem. Unfortunately, we find people side-tracked along one line of thought; they neglect altogether certain dependent factors which are probably far more important than the one line of thought which they are pursuing. In any system of dry induction the only way is to consider all the factors concerned.

I call attention to some work I did a number of years ago, just to indicate one line of difficulty that has not been referred to by anyone else and that most designers of intake manifolds have not considered. It is the effect of the pressure existing in the intake manifold at the various branches or at the various valve-pockets during the sequence of operations. One goes to very great length, for example, to balance an engine mechanically, oblivious apparently of the fact that the great disturbing factor of the whole problem is the variation of pressure in the individual cylinders. If one cylinder is charged with air and mixture at a certain pressure and the next one at a different pressure, we are quite aware of the variation of resulting explosion pressure and the effect that it has upon an engine. The pressure at these various points has not been taken care of by designers and the result is that when we have a mixture which is in a

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more or less unstable condition and subjected to variation of pressure, the gasoline which was previously just in suspension is squeezed out or absorbed in the way that a sponge would operate in a liquid. We may start off with a very fine set of conditions, but if we subject the mixture to variations of pressure and temperature at the wrong places, we are bound to upset the state of conditions which were at first produced by very great skill and effort.

In all discussions upon manifolds engineers seem to make a very casual statement as to the hot air; this mixture was heated, hot air was supplied, and so on. It is not hot air that we want. If we are going to make a dry mixture, of course a certain temperature has to exist or the liquid cannot remain in suspension as a liquid; it will precipitate out. But it is temperature, it is distillation and many other things which have to come into consideration with a complex fuel in order to obtain a certain stable set of conditions. With modern fuels, if we wish to obtain these stable sets of conditions, we must put the fuel into a state where it is able to adapt itself into the required state. Any amount of heat, if the temperature is not sufficient, will never do any good and may do harm.

One other point is that far too much thought is given to the question of mixture of maximum horsepower at maximum engine speed, etc., which is referred to by Mr. Vincent. I think we must sacrifice something, because after all an engine very seldom runs under maximum conditions. We must give a man an engine that operates well with the device provided, under the normal conditions of working to which he will subject this engine.

W. G. WALL:—One thing, already mentioned by Mr. Vincent, seems of very great importance in laying out manifolds; that is to see that the gas does not cool off again after it is once heated. It is rather difficult to accomplish this unless the manifold is inside the cylinder or head. Theoretically we would like to vaporize the gas and then cool it to a point where it is still vapor, but where we get the maximum power. That would be very difficult of accomplishment, especially under varying speeds and loads. Another point in regard to the hot-spot brings up a little experiment I conducted not long ago, in regard to the shape of the manifold and the difference in heating the mixture as to whether the hot-spot is on the bottom of the pipe or in some other posi-

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tion. I think most of us would say that at low speed of the gas the hot-spot should at least cover the bottom of the intake manifold; but by simply making a slight bend in the shape of the manifold so that the gas went direct against the hot-spot, exactly the same object was accomplished, even at low speed of the gas. Therefore, it is a question in my mind whether one of the greatest items is not the shape of the manifold. We are familiar with the experiments conducted in regard to designing the shape of manifolds, so that at slow speed the gas comes in contact with a hot-spot and at high speeds gets farther away, due to the velocity of the gas through the pipe. That seems to work out fairly satisfactorily.

What is Mr. Vincent's idea relating to the heating of the gas after it enters the cylinder and the appreciable difference in horsepower between a water-jacketed combustion space and one that is only partially water-jacketed or not jacketed at all? To my mind, when the combustion chamber is only partially jacketed, even during the small time the gas remains in the cylinder it becomes heated to such an extent as to reduce considerably the horsepower otherwise obtainable.

H. C. GIBSON:—If the miniature carbureter described only delivers a negligible quantity of heat to the mixture under wide-open throttle conditions, I believe it falls short of a full solution of the problem, especially as it cannot aid in preparing for combustion such fuels as boil at very high temperatures. As an aid in starting and general operation under low throttle, the device has evident value, especially because it provides heat just where and when wanted without the introduction of combustion or indirect methods. The consumption of gasoline for this purpose is justified. I take issue with Mr. Vincent that a heater to be practically out of action at wide-open throttle is the condition to be desired. If economy is desired, the heater should be very much in action preparing the liquid fuel for conversion into the dry gas which is distinctly and properly favored throughout his paper.

A tight-fitting choke will aid in pulling a solid stream of liquid gasoline from a nozzle, but I believe that one phase of the solution of easy starting is to furnish a special choking throttle at the carbureter nozzle whereby maximum air speed past the nozzle can result in maximum agitation and atomization of the fuel. Such a throttle should be used only in starting.

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It is true that we are all striving to get the greatest possible power out of the smallest engine, and I agree that it is hard to swerve established custom, but it will be easier to overcome popular trade objection to the use of exhaust heat when it is realized that with such heat controlled to meet the demand for vaporization we have a much more satisfactory engine for all-around utility, economy and power developed per pound of engine weight, if we take advantage of modern ability to produce long-lived high-speed engines.

DR. H. C. DICKINSON:—Mr. Vincent's paper presents for consideration one very practical suggestion for the solution of the problem of heavier fuels. The mixing of freshly-burned hot gases with the intake is unquestionably a very effective means of heating, without the delays incident to heating the manifold or water-jacket. The ingenious design of the device whereby the extra fuel is burned and the extra heat supplied only at partial throttle, in about the desired amounts for good operation, is most interesting. The author is rather modest in his claim regarding overall economy. Considerable improvement in mileage might be expected under all but hot-weather conditions.

Referring to fuel characteristics, while it is quite true that no one characteristic of a fuel can determine its suitability, there are three characteristics which together very nearly determine the value of petroleum fuels, provided only that these are reasonably free from injurious foreign substances. These are the initial boiling point, the end-point and the mean volatility; in other words, the entire distillation curve of the fuel. In the chart showing variations in gasoline from 1916 to 1919 inclusive, the author gives figures for initial point, end-point and specific gravity. It has been pretty generally accepted that specific gravity has no longer any direct relation whatever to fuel gravity. A curve giving mean volatility in place of specific gravity might therefore be more useful.

As regards increasing the power of the Liberty engine by decreasing the temperature, the charge weight is about inversely proportional to the absolute temperature; and it is almost invariably found that the increase in power when the temperature is lowered is much less than would be computed from its increased weight of charge. To get an increase of 20 per cent in charge weight would require a decrease of more than 100 per cent in air temperature, and from all available data this

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would not give by any means an increase of 20 per cent in power unless a change in fuel makes a considerable difference in power, independent of temperature. A large number of tests have been run in the altitude chamber of the Bureau of Standards, in which the temperature of the intake air has been changed repeatedly by nearly 100 per cent, with a corresponding change in horsepower very much less than 20 per cent. A change in fuel from commercial gasoline to aviation gasoline may, however, make a difference of several per cent in power without change of temperature, particularly if the carburetion is not very good.

In reference to spark-plug fouling, it is suggested that the presence of fuel on the sooty deposit on the spark-plug insulator may render this layer conducting. As a matter of fact, gasoline and kerosene are excellent insulators, being about equal to the heavier oils, and should tend to improve the insulation rather than act as conductors. On the other hand, possibly the heavy ends of the fuel absorbed in the sooty layer crack and oxidize on warming up, thus adding to the amount of carbon. Is it not possible that the maintenance of a reasonably lean mixture, or a mixture which is lean at usual driving speeds and loads, will entirely prevent fouling? I am quite satisfied from personal observation that this will result even when wet mixtures are used.

F. C. MOCK:—The question of the temperatures needed for a dry manifold at different throttle positions is of interest. From observation I would say that with our present gasoline of 430 deg. fahr. end-point and about 300 deg. fahr. mid-point, the manifold will be dry when the engine is idling somewhere between 80 and 100 deg. fahr. But to get it dry at wide-open throttle requires from 180 to 200 deg. fahr.; in fact, I have never got it to look dry in any apparatus I have had in use.

I am not sure that it is desirable to have the manifold dry. I think we can get the limit of good operation without having it dry at wide-open throttle; but everything we have tried which brought a satisfactory condition at wide-open throttle, gave enough heat at closed throttle. Practically all of our difficulties are encountered at wide-open throttle, particularly at low manifold air velocities. All the experiments we have made indicate that a properly-designed application of exhaust heat to the intake will give a uniform rise of temperature to the mixture passing by it, regardless of load or engine speed. There

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seems to be a sort of natural automatic regulation, the heat present in the exhaust being fairly proportional to the amount of fuel passing the heating surface.

E. D. THURSTON, JR.:—In regard to the burning of the mixture in the heater, how is the combustion started? I have had some experience in burning explosive mixtures and believe that any delay in starting combustion in this heating device will cause combustion to be set up in the main inlet manifold. Similarly, any interruption in the burning of the mixture in the heater, followed by subsequent combustion, will cause the same effect. It may be that this is a detail that has been worked out, but I should like to know how it has been accomplished. Mr. Vincent has based his calculation as to the heat necessary upon the effect taking place at constant volume; whereas it will actually occur at constant pressure, requiring about 40 per cent more heat.

J. H. HUNT:—The desirability of cooling the products of combustion of the burner before mixing them with the carbureter mixture has been brought out. In some experimental work with a similar device, it has been very interesting to have a window through which one can look into the manifold. With such an outfit in operation I have seen a red flame project into the manifold at least ¼ in. without igniting the mixture entering the engine. This was under wide-open throttle, as the arrangement of the window did not permit viewing the conditions at partly-open throttle. Obviously, with partly-closed throttle and greater suction, the flame would project further; and even under these conditions the mixture is not ignited. It is not easy to account for this failure to ignite, but very evidently it is not necessary to cool the mixture as much as one would suppose.

Such an outfit may not be ideal, because relatively very little heat is supplied under wide-open throttle conditions, as has just been pointed out, but our troubles today come mostly from driving the engine choked when first starting, and when the engine is cold. A device of this type which will accelerate heating the engine and also heat the mixture while the engine is still cold, reducing the use of the choker to a minimum, will very greatly improve the conditions with which we must contend. While in the ideal solution it may be necessary to supply more heat for wide-open throttle work, particularly for lower-grade fuels than we have today, the device which already exists

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takes care very nicely of the conditions we have to meet in automobile engines. Possibly for a tractor engine more heat would be needed at wide-open throttle, because most of the work is done at or near wide-open throttle.

PROF. O. C. BERRY:—I wish to add what emphasis I can to Mr. Vincent's statement that it is time that we devise some system which will insure the realization of the entire useful life of the cars we are designing today. It seems to me inevitable that the fuel to be sold a few years hence will be so much less volatile than our present gasoline that many of the cars built and sold this year will be unable to carburet it successfully. The need for a larger fuel supply is so pressing and so widely understood that some one is reasonably certain to develop a successful way of using more nearly all of our crude petroleum for engine fuel. When such an invention is made, its adoption will be rapid and the petroleum industry will quickly take advantage of the opportunity to change the quality of the fuel put upon the market. Since no one can now predict just what form this invention will take, it might be well to have the intake manifold a separate casting, to give the owner every possible chance to install on his car the inventions of the future and thus be able to get satisfactory service until his car has worn out.

A number of tests carried out at Purdue University are of interest in connection with the question of whether a dry mixture is to be desired in the intake manifold. A Willys-Knight engine was used, mounted on a Diehl electric dynamometer. Except for the small amount of heating through the walls of the short water-jacketed intake manifold, all of the heat for vaporizing the fuel in the mixture was supplied as sensible heat in the air entering the carbureter. The temperature of this air was changed by small steps from 60 to 300 deg. fahr., and the cooling water was kept at about 200 deg. fahr. Under these conditions the engine would not run properly with the 60-deg. air when using gasoline having a gravity of 56.5 Baumé. When the air temperature was raised to 71 deg. fahr., the engine ran more smoothly and gave better power, but still did not operate as it should. With 80-deg. air the operation was satisfactory, except when the leaner mixtures were being used, and the power and efficiency were the highest we were able to obtain. Air at 100 deg. gave about the same power and efficiency as 80-deg. air, but each increase in temperature above 100 deg. caused

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the power to decrease considerably, and the efficiency slightly, until with air at 300 deg. the power had dropped 22 per cent and the efficiency nearly 1 per cent. When the air entered the carbureter at 275 deg. fahr., the mixture was quite dry as was shown by its appearance as it passed through a glass section in the manifold, but lowering the temperature much below this point would produce a fog in the mixture.

To my mind a distinction should be made between requiring a mixture to be dry in the intake manifold and dry at the end of the compression stroke. The latter seems to me to be the essential requirement. Even though wet mixtures do lead to distribution troubles when the manifolding is poor, a mixture that is not too wet can be satisfactorily distributed by a good manifold. The piston-head is hot enough to vaporize a small amount of liquid fuel deposited on it by a wet mixture, and the fog of liquid fuel that remains suspended in the air will be vaporized by the heat of compression. In the Purdue tests the best results were obtained with mixtures that were wet in the manifold. These wet mixtures gave a smooth running engine, a clean exhaust, about 20 per cent more power than the coolest dry mixture and a slightly better efficiency.

Too wet a mixture will cause the engine to miss, and lead to loss of power and efficiency, dilution of the lubricating oil, sooted cylinders and spark-plugs and other serious troubles, as was demonstrated by the Purdue tests run with the 60-deg. fahr. air. This would not, however, lead one to the conclusion that a dry mixture in the intake manifold is the ideal condition.

SYDNEY BEVIN:—One of the members has suggested that the knock in an automobile engine using kerosene or other fuel which produces a typical knock other than the preignition knock, might be caused by the molecules of gas in the exploding mixture vibrating through such an amplitude that they struck each other and that the kinetic energy of these molecules is therefore transmitted very suddenly to the piston and cylinder-head, as would be the case if a mass of gas were detonated in the cylinder. My thought on this subject is that a fuel, such as kerosene or fuel oil, would split under the heat and pressure of compression into three or four explosive gases, and perhaps one liquid which will not vaporize; that the kinetic energy of the exploding gases is transferred to the droplets of the unvaporized liquid, which

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in their turn strike the piston and cylinder-head and transmit shock. It is rather difficult to picture the gas molecules traveling at sufficient speed to produce a knock, whereas the droplets of the unvaporized part of the fuel would be able, owing to their superior mass, to strike a more violent blow. The addition to the fuel of some iodide, as demonstrated in the experiments with different fuels in the discussion of indicators for high-speed engines, might lessen the tendency of the kerosene, or fuel oil, or other fuel, to form the droplets mentioned, thus tending to eliminate the cause of the knock.

J. G. VINCENT:—You probably realize that there is much in what Mr. Crane says about the matter of keeping the mixture going up all the way into the cylinders in this particular job. Frankly, I think this sort of device is of more value in a V-type engine than in a vertical type, although I have worked it out in various types of engines and have failed to find any engine which it did not improve. Of course, it is easier to apply the device to some engines than to others. For instance, with a vertical engine it is possible to arrange the carbureter so that the extra mixture for the burner is taken off the first bend above the carbureter, so that the auxiliary vaporizer is done away with. I mention this as something that can be accomplished under certain conditions. The particular installation that I have shown in the drawings did not lend itself to that form of construction.

We found in early experiments some difficulty in making the engine idle with this device, as well as without it. A little later we obtained results that were slightly better than we were able to get without it. The important thing in getting good idling seems to be to have this burnt mixture come in at the right place with relation to the incoming charge. In the drawings I have shown it coming in at two different sides. It may be better, under certain conditions, to have a sleeve arranged so that the burnt gas will come up around it and form a sort of envelope around the incoming mixture.

Mr. Brewer thinks it would be better to apply the heat on the inside, so as to avoid losses. That is entirely possible and it may be a good idea. It is not one with which I have experimented and it probably presents some difficulties in construction, but it is certainly a good thought.

Mr. Brewer spoke of my decrying the so-called hot-spot manifold. It was not my intention to do so; I simply wished to point out what I think are its limitations. I

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understand that all these devices have their limitations. It seems to me that the difficulty with the so-called hot-spot is that it does not get hot quickly enough, or stay hot enough under idling conditions. Since I wrote this paper I have had a fair chance to check it up and see if what I said was so, because at that time I had not had a chance to operate under severe cold conditions such as 5 deg. below zero and the wind blowing on the car all night. I am glad to be able to advise you that the device operated exactly as it was supposed to operate. It started up promptly and after taking about enough time to back out of the garage and turn around and close the doors, about 2 min., I could drive out of the yard with the mixture set as for normal summer conditions, and jamb the throttle clear to the floor-board. This is a result, you will all recognize, that is somewhat hard to obtain under present fuel conditions.

Mr. Brewer stated that distribution is probably more important than the balance of the engine parts. I wish to concur thoroughly with that thought. I have been all through the subject; it took me a long time to realize that we were really doing many things in connection with balancing engines that did us no good, because we spoiled them all by spoiling the distribution. In comparing two engines, just as often as not the engine that was out of balance showed the best because of the distribution.

I agree that the engine output at high speed is not of paramount importance. I simply wished to state that it is important to keep as much of it as we reasonably can.

In regard to Mr. Gibson's remarks about the necessity from heat at higher speed, I am uncertain as to how far we must carry heat up the range.

Prof. Berry's remarks about the hot piston are of course pertinent. We know that we get splendid operation at high speed under wide-open throttle conditions without this heater. The hot piston will, I believe, take care of the vaporizing of the fuel after it gets into the cylinder. This does not help distribution. Some things are not yet definitely settled. However, in handling the condition up to 30 m.p.h., under steady-throttle conditions, we probably have taken care of at least 80 per cent of the driving, and that part of the driving which certainly gives us the most trouble.

In regard to Dr. Dickinson's remarks about fouling spark-plugs, I have not had time to investigate just what caused the fouling. I do know that we have blamed a

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lot of fouling of spark-plugs upon oiling, when the oiling had something to do with it, but wet mixtures a great deal more. With the mixture properly dried out we do not have any spark-plug trouble, whereas we formerly had considerable. I do not know just what happens.

In regard to my statement about the choker-valve fitting tightly, it is of course important to have a slight leak past this valve at the lowest point, so that the gasoline raised out of the jet will run down to the orifice and meet the high-speed incoming air and be broken up. That is the only way I have found to get good starting. Naturally this can take a large number of materially different forms.

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ADDRESSES AT THE CHICAGO AERONAUTIC MEETING

The meeting at Chicago on Jan. 13, although designated as an Aeronautic Meeting of the Society, was in reality a Mid-West Section meeting. All arrangements were made by the Section and it was therefore natural that emphasis should be placed upon the importance of the Sections by Past-president Charles M. Manly and General Manager Clarkson in their remarks. In addition W. T. Van Orman gave an interesting account of the National Balloon Race held in the fall of 1919.

ADDRESS OF PAST-PRESIDENT MANLY

There is one thing that I would like particularly to say, a thing that is very near to me. I have spoken of it in my recent term of office as President of the Society. It is the importance of the Sections. You have here the very nucleus of what I see as the big work of the Society. The Sections must be developed into strong-going main branches of the Society and the way to do that is to give them all the punch that can possibly be given them in connection with the presentation and discussion of technical papers. It is impossible to attempt to carry on the work of the Society by having a few papers presented at the annual meetings, or by having simply a few papers contributed to THE JOURNAL from time to time. The thing that we most need to build up the work of the Society, to the position that it must be built up to, is to have competition among the members for the honor of presenting papers at the Section meetings and then competition among the people that hear those papers in really discussing them from a technical point of view.

The fact that a paper on any subject is to be presented should be an immediate signal to everyone who has any ideas on that same subject to attend the meeting, and not to attend it with the idea that he is going to gather in information but not give out any. A man who does that usually keeps out a whole lot more than he keeps in.

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The way to get the real advantage of the work of the Sections is to carry on this active presentation of the papers and the active discussion of them, so that in the selecting of papers for THE JOURNAL, we will get the very best papers it is possible to get.

This work of the Society of Automotive Engineers is one of the biggest things that we have in the engineering world, and it will grow to tremendously larger proportions than it has at the present time. My own feeling is that the work of the automotive engineer has just begun. We are going to have, I think, inside of the next ten years, some 20,000 members of the Society of Automotive Engineers. There will be enough automotive engineering work to be done within the next ten years to call for that many more engineers. Whether we shall have them all cooperating in the work of the Society, is going to depend very largely on the work of the Sections. I hope, therefore, that the different Sections will awake to their real opportunity in connection with the carrying on of this work of the Society.

AIRCRAFT

We shall see very important developments in connection with aircraft. We have now come to the stage where the commercial end has to be developed to have any business at all. The Government is not likely to be calling for any large quantity of machines. It will, no doubt, call for a number of machines of different types to maintain the process of building up the aviation service, but the real work of the automotive engineer in the aircraft field must be in connection with commercial aircraft development and operation, and the operating side will be as large as, or larger, than the actual building side.

In the building work we have much to unlearn. The past several years of aircraft development have been devoted exclusively to perfecting the machine as a war machine. Recently we have been working toward a commercial development. There is a tremendous amount to be done in connection with the commercial development. One of the most important things in connection with it is that we shall do our part to get landing fields built. We cannot operate airplanes without landing fields any more than we could operate automobiles without roads, or ships without harbors. The aircraft is today in the same fix as the "Soviet Ark"; it is on its way somewhere, but apparently has no harbor to go into. It is

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drifting around. The appointed harbor has not been designated, at least as far as we know. The aircraft business has to have landing fields just as that ship or any other ship has to have a harbor to go into. If all of our harbors were suddenly taken away, shipping would be in a pretty bad fix; and if all of the automobiles at the beginning of the automobile development had had to operate on country roads and not been usable in the cities, there would have been a very heavy retarding effect on the development of the automobile. We must have landing fields. So it is very important that everyone connected with automotive work do all he can toward assisting the development of them to help along the aircraft work.

The other thing in connection with aircraft work that we all have of necessity to be interested in is to try to get the National Government to take necessary action to provide a unified system of control, so that the States and municipalities will not commence passing all kinds of restrictive laws that will hamper the development work and the actual operation of the machines.

Some excellent plans have been developed in connection with that by the aviation commission that went over to Europe last year under the leadership of Assistant Secretary of War Crowell. These have been presented to Congress in the form of proposed legislative enactments. If the suggestions are carried out, it will be possible to put into effect a really constructive plan of operation that will prevent the passing of all kinds of municipal and State regulations to hamper aircraft operation and hold it back for very many years.

The Motor Truck

The most important thing in automotive work in the way of immediate development is, I think, the motor-truck business. I think that we have not even commenced to get a vision of it. We have a few hundred thousand motor trucks running in the United States. There will have to be several millions running before the country is really properly motorized. We have them operating now under a great many conditions. I think that within the next few years we shall see a tremendous development in the motor-truck business, not only in the building of more motor trucks of more diversified kinds for the different work, but also the building up of very complete data and systems of operation that will

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really give us the same kind of ability to predict the cost of operation that we now have in connection with predicting the cost of construction, or that we now have in connection with railroad operation. So that in the field of motor-truck work, I think that the next ten years will see a good many thousand engineers added, both from the designing and constructing end and from the operating end. Chicago, with its tremendous amount of traffic, should form a very active field for the work of the Society, if the Section here is alive to its opportunities, and that means it is the men who compose the Section that really must have a true vision of what the opportunities are in connection with the Section.

When we come down to it, this matter of vision is really the thing that is most important to all of us. If we have not vision in regard to the future, we will not really exert ourselves in a big way to do the big things that lie before us, and if we have not vision, we ought to acquire it. The vision I see of the work before the automotive engineer for the next ten to twenty years is one of the most fascinating things that a person could possibly contemplate.

I hope that the Mid-West Section will see the vision before it and really work toward the building up of a very active, virile Section here that will make the work of the Society, in this Section, of the great importance that it should be.

ADDRESS OF GENERAL MANAGER CLARKSON

I want to supplement somewhat the excellent outline Mr. Manly has just given of the present and prospective work of the Society. I think there is great suggestive value in what he said.

The Council of the Society as a whole concurs unreservedly in the view that Mr. Manly has given as to the importance of the Sections. The point of the matter is that in the Sections there are not only more frequent opportunities for the members to get together but there is more intimate affiliation between them at Section meetings.

A distinct advance has been made in the matter of the actual adoption of valuable standards in tractor work. There is a more general appreciation of the importance

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of certain types of standards and of the feasibility of formulating and establishing them. With reference to the standards work in general, the Divisions of the Standards Committee have been working well. The reports presented, and accepted for the most part, at the meeting of the Society in January of this year, were more numerous than in any half-year theretofore, and contained much of value to the automotive industry.

Our real work is the securing and disseminating in good intelligible form of technical information, either by way of comprehensive statement of old matters or in connection with anticipating what is coming in the way of development to be reduced to practice. I think we all want to keep in mind constantly that that is our work, the nucleus from which we can be of greatest value to the members individually, the industry as a whole, and in turn the Nation.

There is much broad cooperative work to do. One phase of it has come before the Mid-West Section, in the matter of the possibility of an engineering club being established in Chicago and a building erected to house it. The engineering societies will have to work together more and more as time goes on, because it is obvious that they have much in common, and that which they have in common is of great importance in engineering generally and in connection with the status of the engineer in the various communities and the country as a whole. The theory and logic of the joint procedure are analogous to the common sense of the combined standards work in the different automotive fields, motor-truck, passenger-car, aircraft, motor-boat, farm-tractor, farm engine and isolated electric-lighting plant. The Society is doing and would do in any event those things which apply very largely to all the automotive engineering fields. There are subjects in which the S. A. E. is vitally interested, that are of interest to other engineering organizations and to various Government bureaus. There must be some medium by which all of the bodies actually concerned can work together, avoiding duplication of effort and unnecessary expenditure of money and securing more effective results. There must be also one channel through which we can take up matters of standardization with foreign countries. International standardization is right before us.

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KANSAS CITY TRACTOR DINNER

The fourth annual Tractor Dinner of the Society held at Kansas City on Feb. 19, during the week of the National Tractor Show, was an instructive as well as interesting and entertaining event. Two hundred and fifty members and guests were present, all imbued with the spirit of the impressive exhibition staged by the Kansas City Tractor Club in the form of the show and of the vitally important design, production and economic problems then before the tractor engineers for solution.

E. E. Peake, of Kansas City, presided as toastmaster in a very amusing and satisfying way.

President J. W. Perry, of the Kansas City National Bank of Commerce, addressed the members in a stirring manner and held their interest intently. He told of his own personal experience in the operation of farm tractors and of the confidence that the banks have in the tractor business. He stated that the tractor sales in Iowa, Nebraska, Missouri, Oklahoma and Kansas amounted to $90,000,000 in 1919, citing the further fact that there are approximately 91,000,000 acres of agricultural land in cultivation in this territory. He believed that of the 125,000 or more tractors in use, 50 per cent were in the region mentioned. Mr. Perry predicted that high prices in general would cease.

R. F. Crawford, president of the Kansas City Tractor Club, talked of the needs of the tractor industry as seen by the sales department. He entered a strong plea for the encouragement of development resulting in a few conventional types of tractor, as in the case of automobile production. He also pointed to the automobile industry as a good example of broad cooperation.

O. B. Zimmerman, formerly a major in the Engineer Corps, explained briefly some studies recently made by him. He illustrated vital facts in the matter of the best working speeds of tractors. He based what he had to say upon the principle that a great industry like that of the tractor should be founded on careful investigational and research work. Mr. Zimmerman gave some very important deductions from a coordinated consideration of

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the various data recently published in connection with experiments on plow draft.

ADDRESS OF J W PERRY

While I cannot discuss the automotive business intelligently from an engineering viewpoint, I feel that our interests are mutual because I can lay before you the needs of the farmer, and also bring to you the views and experiences of the banker, now handling to some extent both the manufacturing and distributing departments of this business. You represent the most advanced ideas and the most practical knowledge of automotive engineering of any body of men in the world. You are the planners and builders of the most up-to-date power machinery ever built by man. You are placing in our hands the instruments with which we hope to produce more of the products of our farms at less cost and to lighten our burden by a decrease in the manpower employed. You are attempting to show us that the motive-power machinery you produce will do more with less expense than man-and-mule power has heretofore accomplished. So far, my experience has been in favor of the man and the mule.

The possibilities for advancement and profit through your work are unlimited. We appreciate these possibilities and welcome them, but we have a right to know that we will be properly equipped. We want to know that you possess the creative genius, the business ability and the mutual interest, that will bring to us a product that can be used to advantage. The automobile industry, some ten years ago, passed through this same creative period. The bankers then had some doubts of its economic value, but these have passed and we now think of it as one of the great and important industries of the country. The public paid the price of creating and making the automobile an aid to civilization and industry. It is profoundly wished that you will now bring to us the farm power machine that can be used to advantage, less the cost of experimentation through which the automobile was made useful. It will not be difficult to finance either the manufacture or the distribution of your product, if we are assured of the adaptability of your machines to our needs, and if they are so constructed as to make their use eco-

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nomical. The tractor and other power machines should be just as universally used as the automobile.

I am one of your customers in the tractor line, having been the first user of a power machine in the neighborhood of my farm. My experience was only partially satisfactory. I feel that I paid the price of your experimentation. I purchased a machine that looked adequate and promised well on paper. My mistake was in trying to run a power machine with a mule driver. The agent's statement that the machine was perfectly simple and easy to operate, in fact almost fool-proof, was erroneous. The machine was powerful and when properly adjusted was capable of doing the work of several teams, but I tried to make it do all the work on the place, treating it as a piece of iron and steel and thinking of it as having been made to run forever. I was soon disappointed. The trouble was that when I purchased my machine I did not buy knowledge. The salesman did not sell me the information that I was entitled to; hence my heavy repair bills and unsatisfactory service.

However, the machine served its purpose, and convinced me that a machine properly built and properly sold is a great labor saver. I wanted to know all the good points of my power machine. I plowed all kinds of ground, pulling the drag behind, put in fall crops, baled hay, cut ensilage, threshed, shelled corn, ground feed, sawed wood and dragged the roads. I tried to do what you must finally accomplish, make this power machine work the entire year. I wanted a universal machine, one that would work all the time and do all the work. To accomplish this, we must first have a machine that is adapted to our soil, in fact to all our needs. The man who builds the universal power farm machine that fills the same place as that of the Ford car in the automobile world will be doing humanity a valuable service. I must not overlook the cost consideration; the cost must be made a minimum and not maximum. You must sell us the kind of machine we need, at the right cost; you must also sell *service*. If I had been properly advised as to the capabilities of my first tractor and if my machine had been properly maintained, my experience would have been more satisfactory. Do not sell a machine without selling knowledge with it; it will not run itself; therefore, sell service also. A satisfied customer is your best agent.

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The banker will grant liberal credits on the assumption and proof that the foregoing statements and suggestions are carried out. You will not sell your product on present prices for farm products. All human agencies are now working to reduce high costs. You can have a double part in this by selling your product at the lowest prudent cost and by making your product the means for an increased production. It has been estimated that about $90,000,000 worth of farm implements, including power machinery, was sold during the past year. This is a very large sum, but if properly expended it should bring satisfactory returns. In no other line, however, do I know of any such waste as in farm machinery. Go where you will and you will see the best farm machinery ever placed in the hands of man subjected to the most destructive treatment; no care given to up-keep, the machines exposed to the elements the year around and no thought given to the possibility of making the life of an implement long. This is one of your tasks.

The banker will look with more favor on the time-payment plan when he is assured that the machines you make and sell will be cared for. The principal thing you should have in mind is to produce a labor-saving device that will make for more economical production. Farm labor is getting scarce and for the most part less desirable. It would seem that the Creator made a long day in summer so that man might have more time to make and harvest a crop; but the would-be rulers and dictators of labor have decreed that there shall be less work and more pay, without thought of the equities or necessities of the majority of mankind. Let us not minimize the importance of labor, for we should all be laboring in some field. The man who toils is always entitled to a fair share of the fruits of his labor, but we cannot make and save a crop in this changeable climate with our limited supply of human help in an eight-hour day and therein lies your opportunity.

ADDRESS OF R F CRAWFORD

The needs of the tractor industry are many. I shall speak from the sales standpoint. I come in contact with the tractor industry in many ways and get the views of a great many people who see it from many different angles.

One of the first things needed in the tractor indus-

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try is to make standardized tractors. The more different models of tractors there are, the greater the sale of tractors is hindered. Take, for instance, the types of tractors that are on exhibition at the Tractor Show. A visitor, whether he be a dealer or a farmer who has never used or handled a tractor before, becomes so puzzled by the varied tractor types he sees and the conflicting advice he is given that he has great difficulty to decide what tractor to buy. I do not mean by this that all tractors should be alike, but I wish to show that all these different types and practices are hindering the progress of the tractor industry.

Some of the tractors this visitor has examined are very complicated. All of them look complicated to the man who has yet to learn their mysteries. We do not realize how mysterious these things appear to the man who has not yet been initiated. Some very intelligent people are densely ignorant of the operation of gasoline or kerosene engines. A friend of mine, a car owner, divulged the fact that he did not know what the gasoline did to make the engine go; he knew nothing about how it operated. Another gentleman of my acquaintance, who has owned and used cars for years, went to see a cut-out exhibit of an engine and for the first time in his automobile experience learned the principles of its operation.

It is necessary that engineers work to simplify engines. The fewer things that a farmer has to adjust, the easier it will be for him to operate his tractor and the less expense the manufacturer will have to incur in the way of service. The engineer who develops an engine that is so simple that it is but a matter of a few hours' time for a man of average intelligence to learn its principles and how to operate it, will reap a reward that will fully repay him for the effort. If engineers would consult the sales department when preparing to design a new tractor model I believe they would gain something. The sales department can frequently make suggestions that will avoid having a machine brought out that is not properly balanced. It may be all right from an engineering and a manufacturing standpoint but all wrong from a sales standpoint; or, it may be all right from the sales and engineering standpoints but all wrong from the standpoint of manufacturing. Combining the three requirements is not easy, but an effort to do it is worthy of any engineer's time.

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It may be that it is impossible to simplify the designs of engines and at the same time retain all the good features that engineers feel must be embodied in an engine to make it successful. I feel very sure, however, that it is possible to standardize and simplify the types of tractors until there will be very little more difference between tractors than between the different automobiles of today. Engineers who are designing tractors can learn a good lesson from the way in which automobile designers have proceeded. In general automobile construction is along lines that do not make it so puzzling to users as the tractor seems to be.

It is true that the automobile engine is not worked to its limit of power all the time as is the engine on a tractor. It does not have the same dead load to carry and always has some reserve power. The man who makes provision in the design of a tractor engine to overcome its inclination to give trouble under its dead load, and makes it continue its operation in the same reliable way that an automobile engine does, will have gone a long way toward decreasing the amount of effort that is now required to sell tractors. Tractors are being sold extensively and the supply is not equal to the demand, but the fact remains that a much greater effort is necessary to sell a tractor than to sell an automobile. We all understand that this is not wholly due to the things I have mentioned in connection with the tractor, for the automobile is a pleasure proposition and the tractor is looked upon as an investment, but I am very confident that tractor sales would be doubled if tractors were standardized and simplified to the extent that automobiles have been.

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TRACTOR PLOWING SPEEDS

By Oliver B Zimmerman[1]

Among the problems before the designers of plowing tractors, none is more important than that of ascertaining the most economical plowing speed at which to operate a tractor to give first-class work at a minimum cost. The solution must be right from both the maunfacturer's and the farmer's standpoints. A variety of soil resistances, different speeds, widths and depth of cut, types and shapes of plows must be considered. The recently published draft data of Professor Davidson of Iowa State College and those of the Kansas State Agricultural College are used. They indicate in general that in each kind of soil, whether heavy or light, with speed increase there is a corresponding increase of draft, the amount of which is dependent upon the speed, shape of plow and nature of soil.

The further experiments made relative to increased speed and draft and to the area plowed at different speeds are described and discussed, the results being shown by charts. The conclusions reached are that the acreage plowed decreases markedly with increased speed, that the lower speeds are more desirable than the higher and that time is not gained by high speeds but lost. Seven specific factors affecting the cost of operation are considered in plotting the results and a complete development of draft curve, horsepower curve and number-of-plow curve with relation to miles per hour, is combined in a chart. These lead to ten specific conclusions, which are enumerated.

Among the problems before the designers of plowing tractors, none is of more importance than that of selecting proper plowing speeds. As the variables involved are numerous and elusive, only by careful analysis and experiments can their relative importance be ascertained and the deductions made of value.

The problem is to ascertain the most economical plowing speed at which to operate a tractor to give first-class work at a minimum cost. The solution must be one which will be right from the manufacturer's standpoint as well as from that of the farmer. This means that a variety of soil resistances, different speeds, widths and

[1]International Harvester Co., Chicago, Ill.

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depths of cut, forms or shapes of plows, etc., must be considered. It will be necessary to devote most of this paper to the question of what becomes of the power delivered at the drawbar and to assume certain standard conditions about which the argument can be confined.

First, taking a high-angle view of the situation to simplify the analysis and using two well-designed outfits, one developed to travel at 2 m.p.h. and draw four plow bottoms, and the other drawing two plow bottoms at 4 m.p.h., if it is assumed for the moment that the drawbar horspower is equal and that the acreage accomplishment in the same time is equal, what conclusions can be drawn from the comparison? It is evident that the tractor must move itself and the plows over the ground twice as far in one case as it does in the other, that the number of turns at the ends in one case is double that of the other and that the strains due to striking hidden obstructions are greater at the higher speed. These are the factors which, in the main, require more horsepower ahead of the drawbar at the higher than at the lower speeds, and proper care in design.

Next consider what occurs at the rear of the drawbar. Here it is assumed, to cover a reasonable variety of soil resistance and number of plows, that 15 drawbar hp. is available. It is also assumed that for each speed from 1 to 5 or 6 m.p.h. the engine and tractor are properly designed for the speed considered and of equal fuel economy per horsepower above and below each mile of speed, so that the merging shall be complete and uniform from one into the other and the comparison as fair as possible.

Increased Speed and Draft

For basic data the recently published draft data of Prof. Davidson of Ames, Iowa, and those of the Kansas State Agricultural College are used, as these tests are in complete agreement with experimental data developed by experienced commercial organizations in the past and used by them in present-day designs. The data mentioned indicate in general that in each kind of soil, whether heavy or light, with the increase of speed there is a corresponding increase of draft, the amount of which is dependent upon the speed, shape of plow and nature of soil.

Fig. 1 is typical and represents much of interest in that between the limits of the experiment, over a range of speeds not too far from the designed rates for the various kinds of plowshare, the plows show a uniform

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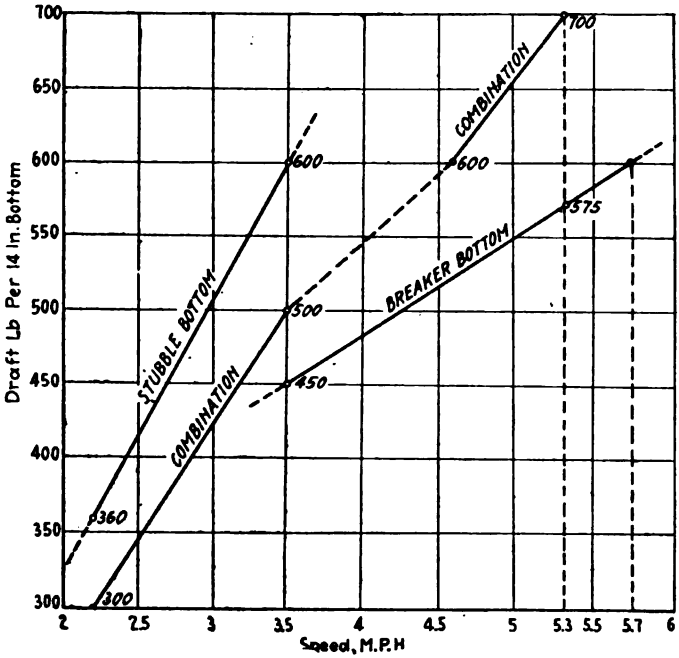

FIG. 1—UNIFORM INCREASE IN DRAFT WITH AN INCREASE IN SPEED

increase in draft with an increase of speed and the draft is illustrated by a straight line. The combination plow bottom was experimented with at two speed ranges. It should be borne in mind that the soil resistance is very small in these Kansas tests. In percentages, with a stubble plow bottom in light soil, for an increase of 1.3 m.p.h. above 2.2 m.p.h., the draft increase is 240 lb. or, stated in percentage, a 59 per cent increase of speed causes a 75 per cent increase in draft. For the combination plow bottom there is a similar set of figures; a 59 per cent increase of speed causes a 66 per cent increase of draft. With the breaker plow bottom, a 16.3 per cent increase of speed, 3.5 to 5.7 m.p.h., causes a 33 per cent increase of draft, 450 to 600 lb. The deduction is clear. With the increase of speed there is a proportional increase of draft and the less abrupt moldboard has the least resistance. The same is shown in Prof. Davidson's data (See Fig. 2), where an increase from 2 to 4 m.p.h., or 100 per cent, causes a draft increase of 33 per cent.

Next taking up the horsepower required to perform the operation and translating the speed and draft into

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power, it will be noted from Fig. 2 that not only must the work due to the added speed be accomplished but in addition the added percentage of draft must be provided for. Hence it is found on this chart that in speeding up from 2 to 4 m.p.h., a 100 per cent increase of speed requires an increase from 4.48 to 11.95 hp. per plow, or 267 per cent.

Fig. 3 is a diagram of horsepower required, illustrating the relations for the Kansas tests and their position to a constant increase line, emphasizing again that at both

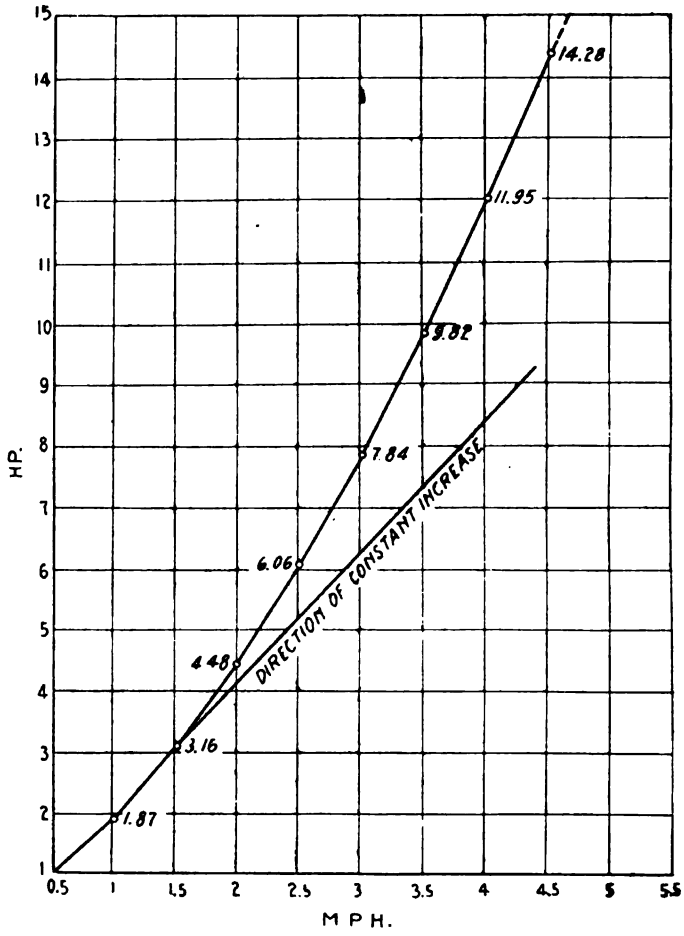

FIG. 2—HOW INCREASING THE PLOWING SPEED INCREASES THE DRAFT

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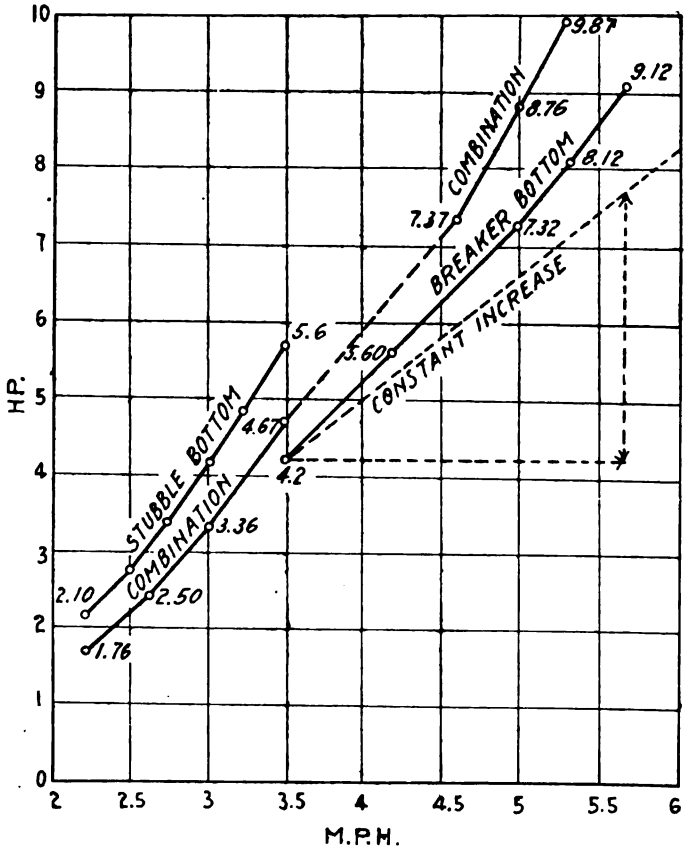

FIG. 3—HORSEPOWER REQUIRED AT DIFFERENT PLOWING SPEEDS

low and high speed the effect of increased speed is to reflect itself in much increased horsepower.

Fig. 4 was developed from the tests, giving a comparison of various sizes of tractor operating at various speeds and in various resistances of soil. Data were obtained by determining at the various speeds how many plows the tractor indicated would pull. By cross-reading from any given soil resistance at the left and from a point indicating the number of plows, the speed at which they can be pulled is shown at the curve; 575-lb. soil at 2 m.p.h., four plows, 15 drawbar hp. curve, reads 2½ m.p.h. Likewise, a given tractor speed followed to the curve and then to the left to intersect a vertical line, records the full

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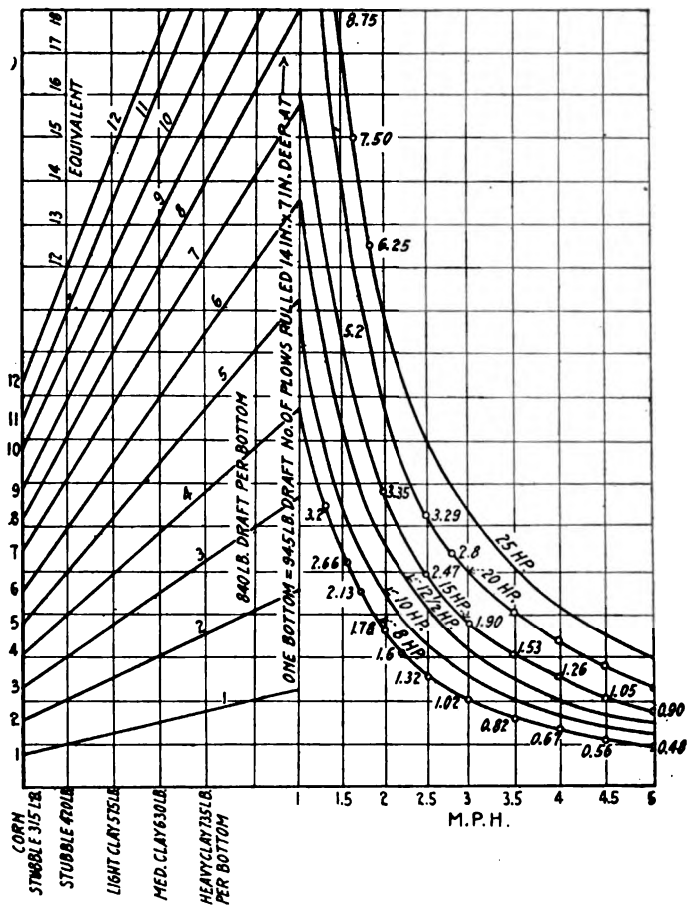

FIG. 4—COMPARISON OF DIFFERENT TRACTORS OPERATING AT VARIOUS SPEEDS WITH DIFFERENT SOIL RESISTANCES

number of plows to pull in that soil; 2 m.p.h., 10 drawbar hp. curve, 630-lb. soil at 2 m.p.h. reads three plows.

AREA PLOWED AT DIFFERENT SPEEDS

With the data indicated based upon careful tests in light soil, the acreage plowed per hour by the tractor at various speeds and in various soils can be plotted as in Fig. 5. By calculation, the curve swinging downward and to the right represents the curve of maximum area or acreage which can be plowed economically at the speeds

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shown, in the soil indicated and with the designated 15 drawbar hp. Intersecting this curve are various radial lines designating the path on the field of various numbers of plows cutting 14 in. in width. A different series of radial lines would be drawn should 10 or 12 in. or other bottoms be under consideration. This chart is very in-

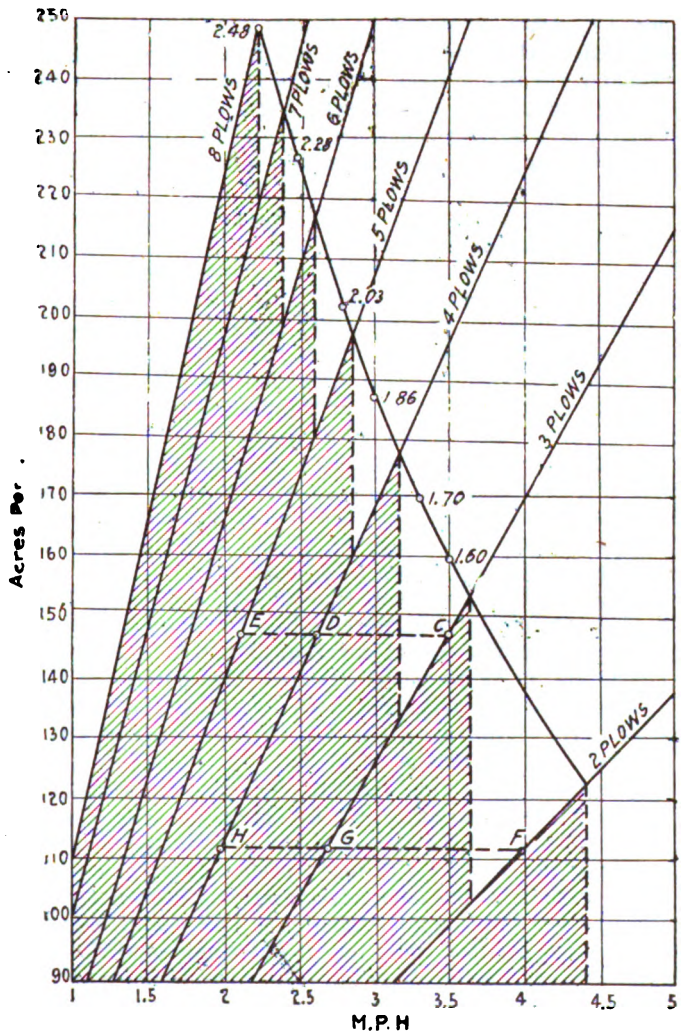

FIG. 5—ACREAGE PLOWED PER HOUR AT VARIOUS SPEEDS

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structive because it explains many factors which are confusing or hard to explain when field accomplishments are analyzed.

The sawtooth lines indicate that a 15 drawbar hp. engine, in this soil, starting at 2 m.p.h., would begin by plowing at the rate of 2.20 acres per hr. The acreage would increase with an increase of speed up to 2.50 acres per hr., when a speed of about 2.25 m.p.h. has been reached. At this point the drawbar horsepower has reached 15 and a plow is dropped off, continuing with seven plows, from 2.20 acres. Again, as the speed advances, the acreage increases until the seven-plow line cuts the maximum when another plow is dropped, and so on.

Now considering that three tractors are at work under the same conditions and drawbar horsepower, operating three, four and five plows, which are designated respectively as *C*, *D* and *E*, at such speeds as will cause each to plow 1.47 acres per hr., what can be deduced from the location of these three points? First, the three-plow rig is working nearer its maximum than the four or five-plow rigs, since the distance from the maximum is increasing or, in other words, *C*, *D* and *E* are not requiring 15 drawbar hp. and the five-plow outfit is using the least horsepower of the three to plow the same acreage in the same time. Utilizing the full 15 drawbar hp., the acreage is in the relation of three plows to 1.54 acres, four plows to 1.78 acres and five plows to 1.97 acres.

Again, taking the point *F*, a two-plow outfit operating at 4 m.p.h. covers 1.13 acres while the same outfit fitted with eight plows would cover at 2 m.p.h. 2.22 acres or nearly 100 per cent more acreage. The maximum condition using 15 drawbar hp. with two plows is 1.25 acres, while with eight plows it is 2.43 acres, approximately 100 per cent more acreage.

Admitting that this diagram does not compensate for the increased weight drawn of the eight over the two-plow rig, nor for the fact that the plow shape is not correct for the widely different speeds, nevertheless, it is positive that as the comparative speeds decrease so that the two are only small percentages above and below the designed speed for the plow under given conditions, the identical relation holds true. The corrections mentioned would tend to reduce somewhat the acreage at the lower speeds to an extent covered by the power absorbed in hauling the added weight of the greater number of plows

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over the ground, and the greater speeds would reduce the available plowing energy.

Where heavy land is under consideration, much the same conditions are met and analyzed in Fig. 6. It is clear from both Figs. 5 and 6 that the *acreage plowed decreases markedly with increased speed* to such an extent that correction in moldboard design or reductions in

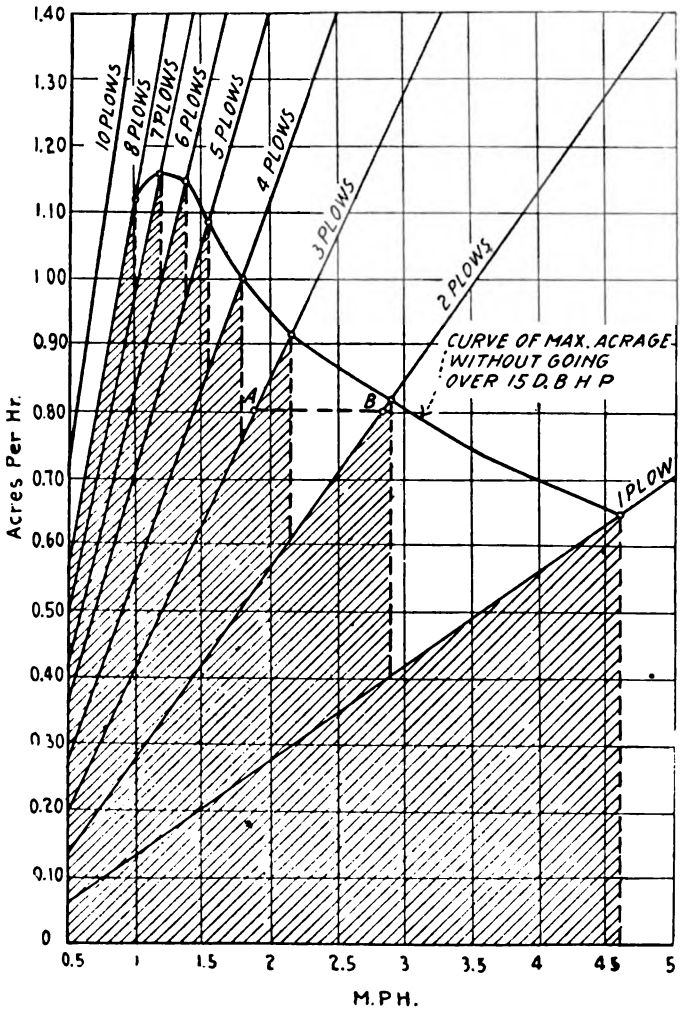

FIG. 6—AREA PLOWED AT DIFFERENT SPEEDS WITH 15 DRAWBAR HP.

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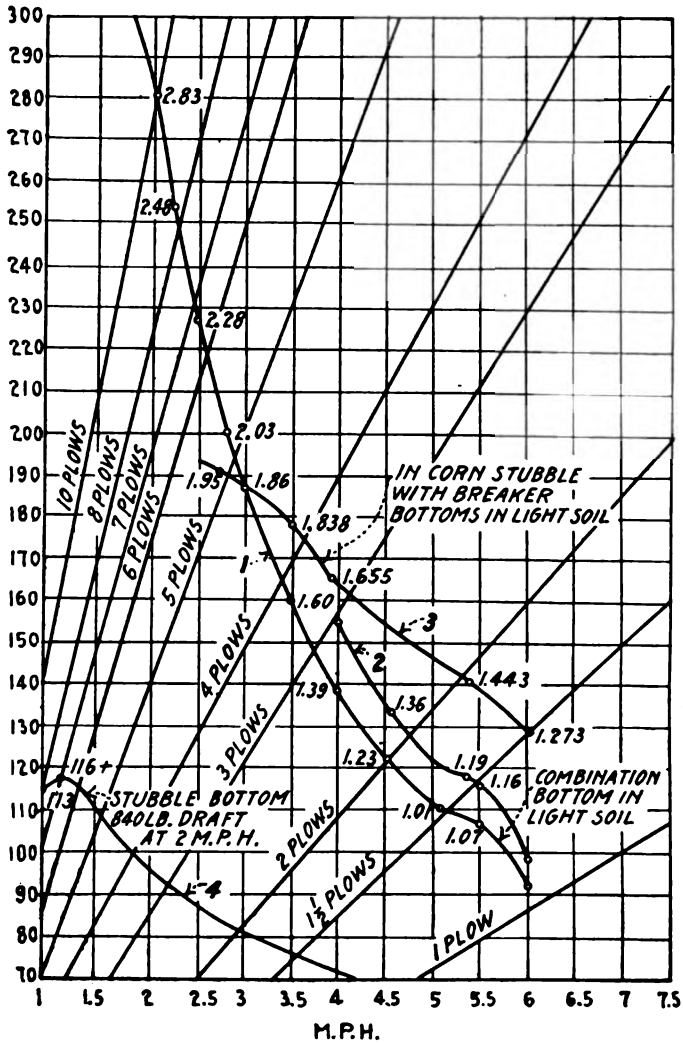

FIG. 7—COMBINATION DIAGRAM OF THE AREAS THAT CAN BE PLOWED WITH DIFFERENT PLOW BOTTOMS

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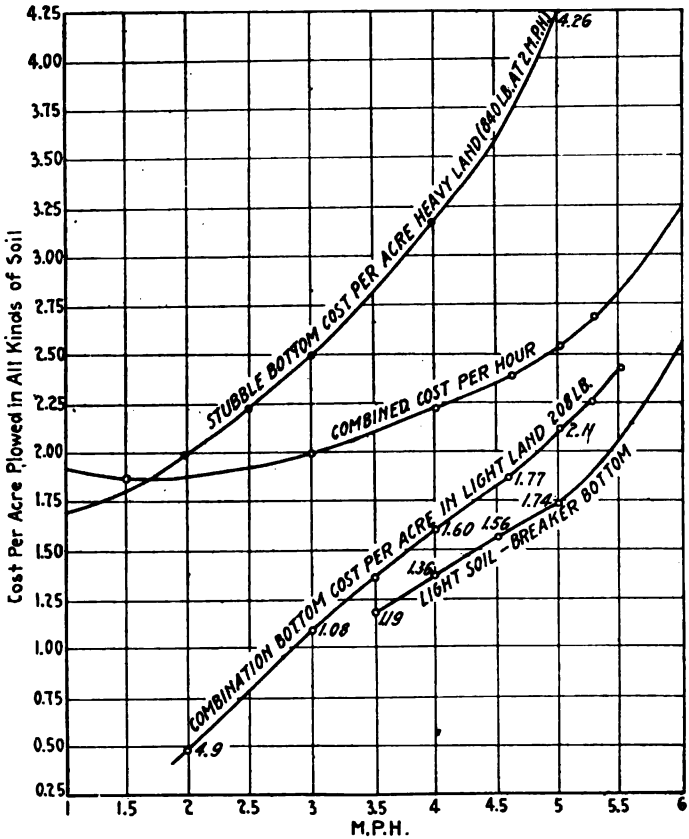

FIG. 8—COST OF OPERATION AT DIFFERENT PLOWING SPEEDS

weight cannot overcome the deduction *that the lower speeds are more desirable than the higher.* It is also clear that time is not gained by high speeds; in fact, time is lost.

Occasional analyses of field demonstrations have led to wrong conclusions because the machines were not being compared on an equal basis, a condition quite impossible to attain except theoretically as shown. Two cases to illustrate this in heavy land are detailed in the table at the bottom of page 482.

This indicates that the ability to win, in a plowing contest, for instance, is dependent upon the relations which exist at the time and not necessarily upon the

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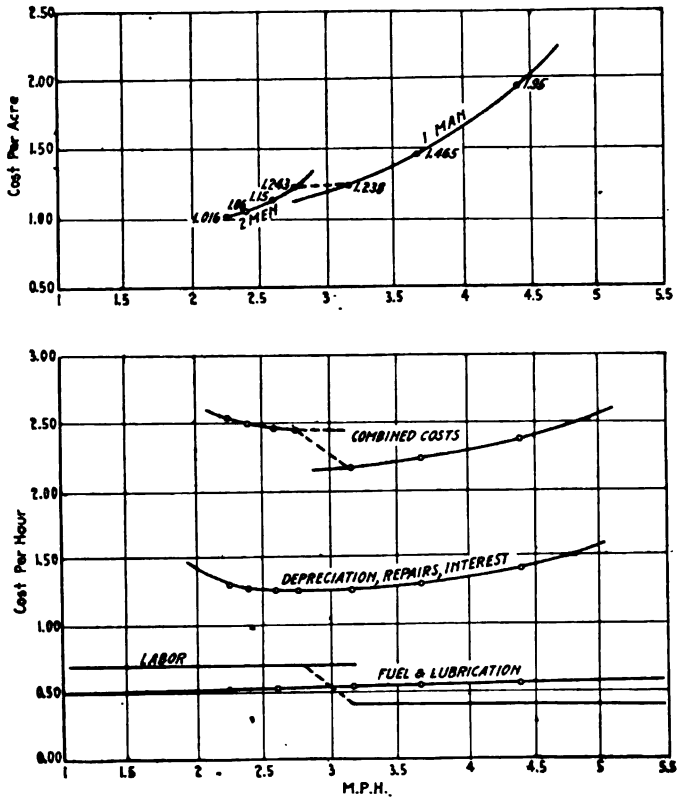

FIG. 9—COST CURVE BASED ON TWO-MAN OPERATION AND THE COST OF PLOWS, ENGINE AND EQUIPMENT

efficiency of the engine and outfit, but upon the relations of the possibilities of adjusting the speed and number of plows so as to operate close to the line of maximum acreage. In this case the low speed wins once and loses once, but if the speed of 3 m.p.h. or over were attempted by either tractor in this land it would be unable to pull more than one plow. Similar comparisons in Fig. 5 are

Tractor	Number of Plows Pulled	Gear	Speed, m.p.h.	Area Covered, acres
1	3	Low	2.20	0.92
2	2	Plowing	2.75	0.80
1	2	Plowing	2.75	0.80
2	3	Low	1.75	0.75

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more in line with actual experience, as the deductions are clearer, although this soil resistance is less than usually obtains.

Fig. 7 combines the various acreages with the different plow bottoms in one diagram. Aside from the correct determination of the proper plowing speed, there arises the question of the desirable speed for hauling equipment such as threshers and wagons over the road, the drawing of mowers, binders and similar farm equipment in actual

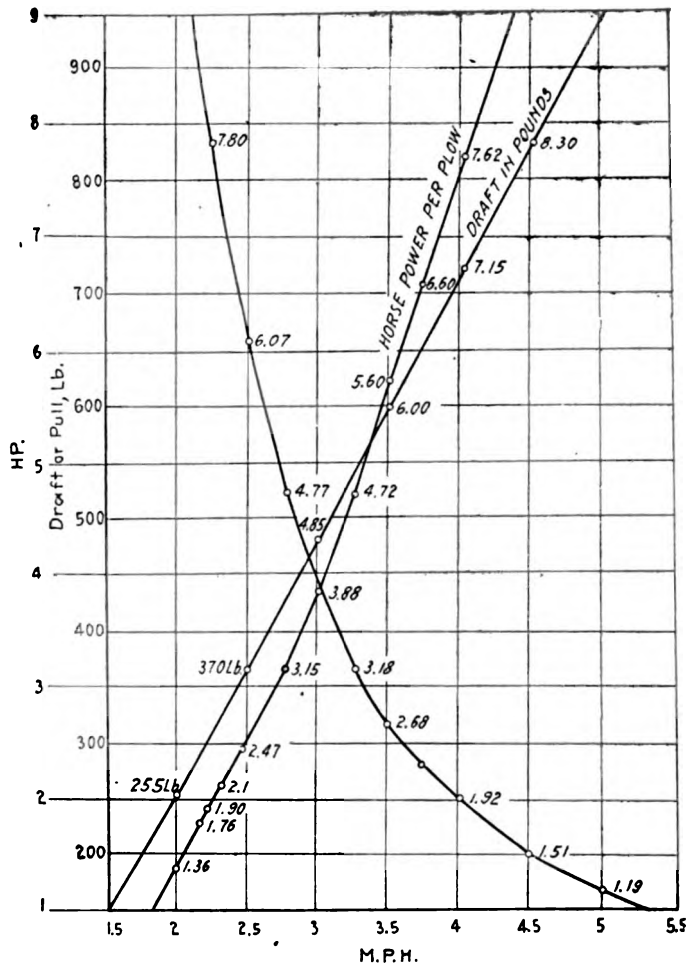

FIG. 10—RELATION BETWEEN PLOWING SPEED AND DRAFT, HORSE-POWER PER PLOW AND NUMBER OF PLOWS

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operation. This question is outside of the discussion. New apparatus could and will be designed for higher speeds, but it must be evident to those with experience that the percentage of increase in economic workable speeds cannot be far from those deduced from this analysis.

Cost of Operation

Data on this subject have been used in plotting Fig. 8, which are indicated by experience covering the following:

(1) First cost of 25-hp. tractor, plows, tanks and supplies, a constant, $2,500
(2) Interest on the investment at 5 per cent
(3) Depreciation on the basis of 8½ years at 2 m.p.h. to 6 years at 4 m.p.h.
(4) Repairs, on an increasing rate from 6 per cent at 2 m.p.h. to 8½ per cent at 4 m.p.h.
(5) Labor, at 40 cents per hr. and 30 cents per helper on over four plows
(6) Fuel and lubricant for quantity on the basis of 5 per cent added for each mile of increased speed, at the market prices and on the basis of 65 per cent transmission efficiency at the drawbar
(7) The hours of operation to be figured at 500 per year, based upon U. S. Government records

It is clear that the cost rises rapidly with the speed.

The same facts have been used in Fig. 9 introducing the two-man operator feature and charging the actual cost of plows, engine and equipment used, as compared to the constant cost shown in Fig. 8.

A complete development of draft curve, horsepower curve and number of plow curve with relation to miles per hour, is here combined in one chart in Fig. 10. From this, therefore, the conclusions follow that

(1) Placed upon a comparable basis and with reasonable assumptions supplementing the carefully prepared and conducted experiments used, the most economical plowing speeds are unquestionably below 3 m.p.h., the cost rising rapidly from about 2 m.p.h.
(2) None of the variables which have been left out of this discussion can enter into the question to a degree that will overcome the evidence indicated by these charts
(3) If plows were designed to meet higher speeds they can help only in reducing the greatly increased costs at the higher speeds, but they cannot by any means veer the economic point above 3 m.p.h.

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(4) The argument for better breaking up of the soil at the higher speeds is heavily paid for, and it is more economical to perform the operation of harrowing either separately or behind the plows than to try to accomplish it by rapid plowing

(5) To attain the very best results with the plowing outfits, speed ratios of plow gearing and throttle should cover the ranges from 1¾ to 3 m.p.h. This would permit the most flexible ranges to meet the various soil resistances (See Fig. 4)

(6) From Fig. 6 it appears that in heavy land and in plowing up to 8 in. in depth with small tractors, greater acreage would be attained by the use of 10 or 12-in. instead of 14-in. plow bottoms, since more of the sawtooth points will thereby meet the economical acreage curve. A better adjustment of cutting width is also possible

(7) The time required to plow 1 acre can be tabulated from these tests, with relation to the number of plows pulled, as follows:

Number of Plows	Heavy Land, hr.	Light Land, hr.
2	1.212	0.643
3	1.095	0.565
4	1.000	0.506
5	0.926	0.462
6	.....	0.426
7	.....	0.400

(8) The low limit of plowing speed is obviously the speed which will permit the proper scouring of the moldboard. This speed will be dependent upon soil conditions. The proper moldboard is assumed to have been chosen, i. e., one whose abruptness and scouring qualities are correct for the conditions to be met

(9) The cost diagram, using two operators at low speeds and with five or more plow bottoms, can be further cut by using power lift equipment where one man can operate up to eight plow bottoms

(10) This presentation indicates that much needed work can be carried out experimentally to improve both engine and plows, with results of considerable economic value to the industry, and it should cause a series of important discussions to follow the analysis.

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MOTOR BOAT MEETING

At the Motor Boat session of the Society held at New York City on the evening of Feb. 25, much of interest was presented in connection with the plans of the Society as to standardization work in the marine field, as well as several papers of decided value to those engaged in the design and production of motor boats and engines and parts therefor.

Joseph Van Blerck, chairman of the Marine Division of the Society's Standards Committee, presided and opened the meeting with a convincing statement as to the necessity of securing the support of the members of the standardization work which he explained is of great value and possibility to the motor boat industry. He argued, in addition, that the Society should hold frequent meetings at which motor boat engineering subjects would be taken up. There are encouraging signs that engineers and draftsmen working in the motor boat field will indicate in a concrete manner their appreciation of the benefits to be derived at joint engineering deliberations.

George F. Crouch, professor of naval architecture at Webb Naval Academy, discussed present-day requirements of marine gasoline engines as imposed by the design and service conditions of power boats. He stated that at least three types of engine are needed to meet the demands in this connection.

Commander Holbrook Gibson, of the Submarine Repair Base, League Island Navy Yard, Philadelphia, discussed extemporaneously the Diesel engine as installed in German submarines, speaking specifically of U117. After the signing of the armistice Commander Gibson inspected forty of the German submarines that were first surrendered and afterward the remaining portion of the German submarine fleet. He explained that practically the entire German submarine fleet was equipped with the four-cycle Diesel engine built by the Machinenfabrik Augsburg-Nürnburg in four sizes of 300, 550, 1300 and 1750 hp. respectively. All of the engines are six cylinder, except the 300-hp. installation which is ten cylinder. Commander Gibson commended highly the design and workmanship of the German submarine Diesel engine.

Mr. Van Blerck spoke on the possibility of quantity

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manufacture of marine engines adaptable for other purposes. He explained that the marine engine must be capable of running under full load for an indefinite time at an inclination of 12 to 15 deg. He told of a plan in the observance of which it was expected that the marine engine should have the advantages of quantity production. He exhibited views of a farm tractor engine, one of the features of which was a gear-driven fan. The flywheel of this engine which was designed for use in motor boats and motor trucks, also is mounted in the rear. He announced that his experiments had indicated that it is not necessary to have both engines running outboard in a twin-screw boat; that is, that both engines can run in the same direction without objectionable operation. The advantage of such an arrangement is, of course, the possibility of using two "standard" engines in such construction, avoiding the employment of different directions of rotations of the oil-pump, magneto, water-pump, generator and starting pump, as well as the need of different camshafts.

Mr. Van Blerck also referred to the sliding reverse gear which had been incorporated in the powerplant described, this being an innovation in the marine field except in relatively few cases where automobile engines had been used in motor boats together with an automobile transmission. In this reverse gear installation the reverse speed is 82 per cent of the forward speed.

W. C. Davids presented, as collaborator with O. P. Sells, an abstract of papers presented at earlier meetings of the Society containing data on piston performance in engines.

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COMMENTS UPON FUELS, LUBRICANTS, ENGINE AND PISTON PERFORMANCE

By William C Davids[1]

The comments the author makes regarding fuels, lubricants and engine and piston performance are suggested by pertinent points appearing in papers presented at the 1920 Annual Meeting of the Society. A list of these papers is given. The subjects upon which comments are made include salability of a car, engine balancing, pressure and chemical constitution of gasoline at the instant of ignition, the use of aluminum pistons, the success attending the various departures from orthodox construction, gasoline deposition in the crankcase and cleanness of design, as stated by Mr. Pomeroy; the performance of a finely atomized mixture of liquid gasoline and air and the contamination of lubricating oil by the fuel which passes the pistons, as discussed by Mr. Vincent; the dilution of lubricating oil in engine crankcases and the saving that can be effected by its prevention, as mentioned by Mr. Kramer; and tight-fitting pistons and special rings as presented by Mr. Gunn.

The author's remarks are largely focused on pistons, rings and lubrication.

The comments I shall make regarding fuels, lubricants and engine and piston performance, are suggested by some of the pertinent points appearing in the following papers presented at the 1920 Annual Meeting of the Society:

Tendencies in Engine Design (By L. H. Pomeroy)
Dilution of Engine Lubricants by Fuel (By Gustave A. Kramer)
Adapting Engines to the Use of Available Fuels (By J. G. Vincent)
Aluminum Piston Design (By E. G. Gunn)

The quotations are as stated and my comments thereon are appended.

> Mr. Pomeroy:—If there is one thing certain, it is that a bad car is not salable very long, even by the most skilled sales department

The facts seem to support this statement in the main; yet engines are being sold in which the manufacturers

[1]Supervising engineer, William Gardner & Co., Rutherford, N. J.

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have made little or no attempt to alleviate the inherent faults which have been mentioned in the papers being considered.

MR. POMEROY:—Engine balancing has also been the subject of much attention

Crankshafts have been hollowed, crank-throws counter-weighted, rods and pistons lightened, and much minute care has been taken to have the mechanical moving parts balanced. The major factors in balancing an engine during the development of power are those mentioned in the foregoing papers, including dry fuel thoroughly mixed and warmed at the time of ignition, an even and rapid flame-propagation rate and a proper lubrication of parts.

In these papers there is no mention of uniformity of compression or of the pressure required which will best facilitate the obtaining of a dry fuel mixture and an increase in temperature, so as to permit ease of ignition and a rapid and even flame-propagation rate. Uniform compression cannot be obtained without perfect valve and valve-seat contacts and having the pistons properly packed. Engines that have more or less variation of compression in the different cylinders, from 5 to 20 per cent frequently in actual operation, are much more out of balance than engines not having carefully balanced crankshaft, rods and pistons. The mechanical balancing of the engine can and should be made effective by packing the joint between the wall of the cylinders and the wall of the pistons so that it will not leak. A uniform compression can then be obtained and the pressure increased, so as to raise the temperature of the fuel, increase its dryness, impregnate the air with the gasoline in minute particles, provide ease of ignition and assist in a rapid flame-propagation rate.

MR. POMEROY:—In a mixture of gasoline and air, it apparently depends upon the pressure and chemical constitution of the gasoline at the instant of ignition rather than upon the temperature

Mr. Pomeroy presumably refers to the temperature obtained by preheating.

MR. VINCENT:—It is conceivable that a finely atomized mixture of liquid gasoline and air can be made to perform as well as a dry mixture

MR. POMEROY:—The use of aluminum pistons enables the inertia forces in a four-cylinder to be reduced very considerably below those in an eight-cylinder

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engine of the same capacity using cast-iron pistons and if aluminum connecting-rods also are used the wear and tear on the engine is cut literally in half at the source

Yet in the face of this statement, manufacturers are this year abandoning the use of great quantities of pistons which are such an ally to the smooth, quiet and efficient operation of the engine. Is it not due to the fact that the aluminum pistons are more difficult to pack than cast-iron and that sufficient care and thought have not been directed to sealing the joint between the cylinder and the piston wall?

MR. POMEROY:—The success attending the various departures from orthodox construction is a very useful object lesson that no established construction is beyond improvement

The method long in use, comprising the turning of grooves around and into the pistons and snapping into them a ring made of cast iron, of many different styles or patterns, merely because of previous practice, has been what might be termed orthodox construction. Is it not high time that these old methods were made obsolete and that pistons be packed in a practical manner?

MR. POMEROY:—The subject of gasoline deposition in the crankcase is one of more practical importance than a problem involving physical speculation. With prewar gasoline the maximum absorption was about 4 per cent. Nowadays, when fully one-third of standard gasoline does not vaporize under a temperature of 140 deg. cent. (284 deg. fahr.), deposition is much more serious

MR. VINCENT:—The third item in order of importance insofar as the owner is concerned, is the contamination of the lubricating oil by the fuel which passes the pistons. This is a serious problem, for few owners will go to the trouble of draining off the oil at comparatively short intervals. In consequence, the lubricating system soon becomes filled with a mixture of fuel and oil of little or no lubricating value

MR. KRAMER:—Parallel with the decline in the volatility of commercial gasoline, complaints have appeared with increasing frequency of engine lubrication troubles resulting from the dilution of the lubricating oil in engine crankcases. The trouble is particularly pronounced in tractor engines where economy demands the use of the cheapest possible grade of fuel. How much of the trouble reported

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is really caused by dilution of the lubricant would be difficult to trace. Nevertheless it must be admitted that the problem does exist and that it is becoming more serious with the steady decrease in volatility of internal-combustion engine fuel. Inasmuch as this decrease is due to an increased demand, no relief through an increase in volatility of the fuel is in sight. The situation must then be squarely faced by the engineers of the country and attacked from every direction that promises a solution of the problem

The first and most satisfactory solution of the problem is to prevent dilution of the oil

Moreover, even the best fitting pistons and rings allow some of the cylinder charge to leak into the crankcase during compression

The statements of these engineers definitely bring the seat of the trouble to the unobstructed passage from the combustion chamber to the crankcase, by way of the space between the walls of the cylinders and the walls of the pistons. If the best fitting pistons and rings allow passage of fuel or oil, it is evident that they do not function to accomplish their purpose and therefore are faulty in design, application or material. A definite theory should be evolved for packing the piston, and from this theory a standard method should be developed which will prove successful in practice. When this has been accomplished, the old orthodox rule will be greatly disturbed if not definitely abandoned. Mechanics will then become as accustomed to grinding piston packing rings to their seats on the flanges of the piston as they are now accustomed to grinding valves to their seats; this should be so, as the valves and the piston packing are holding against the same chamber content. Why favor one and neglect the other? Cylinder walls should be straight, round and well finished, so that the packing can readily obtain perfect contact with the cylinder walls and maintain such contact indefinitely.

MR KRAMER:—The saving effected with engines requiring a frequent renewal of the oil on account of excessive dilution, would soon pay for the cost of the additional equipment, even at the present high price of lubricants

The orthodox rings can be enumerated as the plain, the angle cut and the lap-joint types, either eccentric or concentric. The majority of engine manufacturers are using a ring of one of these forms. Practice for the past fifteen years has proved that the joint between the

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walls of the cylinders and the walls of the pistons cannot be closed with rings of these types. The statements of the authors, to which reference has already been made, support this statement. It is therefore apparent that the method of packing pistons which has been in vogue for years should be made obsolete and a more practical and efficient method devised.

The valves have a continuous seat surface. Such a surface is provided on the flanges of the grooves of the pistons and is applicable for the seating of piston-rings. The valves have a continuous face for seating and, when ground to the seat as mentioned, make a closed contact between the valve and the seat and prevent the passage of combustion-chamber content during compression.

Piston-rings have been produced that provide a continuous-ring seating face. If this face were ground to the seat of the piston-groove flange, in like manner to that in which a valve is ground to its seat, there would be no material passing that joint. It then remains to close the gap at the ends of the ring, and to seal those ends against the wall of the cylinder. When this is accomplished and the rings make full contact with the inner circumference of the cylinder, the gap between the piston wall and the cylinder wall will be closed. There should then be no passage of fuel or residue from the combustion chamber by way of the pistons. This method provides for the packing of pistons against compression, and against compression only. It does not follow that when a piston is practically packed against compression it is packed against suction also. For obvious reasons it is much more difficult to pack a piston against suction than to pack it against compression.

MR. GUNN:—When too much oil is thrown into the cylinder bores, tight-fitting pistons and special rings will not completely overcome the trouble

A similar statement was made by H. Cooke when discussing Diesel engines at the January, 1920, Pennsylvania Section Meeting. Each of these statements has reference to lubricating oil passing the piston and going up into the combustion chamber, producing the undesirable conditions with which all are familiar. To prevent the passage of the lubricant upward along the piston and into the combustion chamber, it will be necessary to pack the joint in like manner to that described for compression, except that the seat contacts of rings and groove flanges will need to be reversed and made at the

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top of the ring-groove flange, not at the bottom as for compression. When this has been accomplished, the problem of obtaining sufficient wall tension of the ring presents itself, for, unlike packing for compression, there is no compression back of the suction ring. Naturally, the suction ring would need to be in the first groove above the wrist-pin, functioning so as to shut off the passage of oil and air at that point and thus preventing its passage from the crankcase to the combustion chamber. The only pressure that would be effective against this suction ring, would be that of the difference between the atmospheric pressure in the crankcase and the suction vacuum in the combustion chamber. It leaves the functioning of the ring dependable upon the inherent expansion tension which has been developed in the ring. Assuming that the tension of the ring is 10 lb. per sq. in. and that the ring is ¼ in. wide, there would be 2½-lb. pressure exerted per lineal inch of ring. This is sufficient pressure to hold the ring against the wall when oils having a viscosity of about 250 deg. are used, and sufficient drainage is provided through the wall of the piston to provide egress of all excess oil that is in transit between the cylinder and piston walls. When an oil having a greater viscosity is used, the pressure it creates against the ring increases to the extent that the ring is caused to collapse and recede into its groove, permitting the oil to pass on up and past the piston into the combustion chamber. In instances of this kind, it is practicable to place a second ring on the piston in like manner as the first, except that it will not be necessary to provide the same amount of drainage.

Mr. Cooke also stated that the Diesel-engine cylinder must be lubricated without excess, and that gravity lubrication is suitable for use on engines with trunk-type pistons. This becomes a very practical method of lubrication for the large-type engines when the pistons are packed in the practical manner here described, and is much more simple, efficient and cleaner than that of the spray system from the crankshaft.

Pistons that are lubricated by the oil-spray from the crankcase and are so poorly packed as to permit unconsumed fuel and combustion residue to pass to the crankcase, give off an offensive odor when the crankcase is opened. Commander Gibson, in charge of the Diesel engine of the German submarine U-117, at the Philadelphia Navy Yard, stated that he and his men could

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readily detect a good engine from a bad one by the odor it emitted.

> MR. POMEROY:—Cleanness of design, both outside and inside, is being appreciated more every day. The day is rapidly approaching when the public will demand that the automobile shall not be a means of transportation only, but susceptible of artistic treatment in just the same degree as a yacht or a house. The first law of beauty in construction of any kind is that the part shall be the one best fitted for the purpose

Pack engine pistons practically, in the manner best suited for this purpose; eliminate the flow of fuel and lubricants past them; annihilate the tell-tale odor; prevent the waste of fuel and lubricants and improve the maintenance.

THE DISCUSSION

CHAIRMAN JOSEPH VAN BLERCK:—I think that Mr. Davids' views are well stated as regards stopping the oil from passing the pistons, but that as to keeping the unburned fuels from passing the piston, he is starting at the wrong end. With perfect combustion there need be no concern about the piston, as far as allowing the unburned fuels to pass it is concerned. I have been watching this. On marine engines there are water-jacket manifolds and they are necessary, but a great many engines have been ruined in the past by the building up of the lubricating oil in the crankcase, since we have been forced to contend with the heavier fuels. On the engine we are building we have a hot-spot manifold. We are satisfied that we have excellent combustion and that we have it immediately after the engine is started. The exhaust manifold will in some cases become fairly hot, but we feel that this slight advantage is well enough off-set to be disregarded when we consider the great advantage we are obtaining. We are not concerned about the pistons; the better pistons we can make the better we can pack them and the more oil we can circulate through the bearings. Some years ago when we first started the pressure oiling system our task was to keep the oil away from the cylinders; but as we made better pistons and better piston rings we were able to increase the oil pressure. We hope in the future to put considerably more oil through the bearings than we are able to put at present.

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THE DIESEL ENGINE OF THE GERMAN SUBMARINE U-117

By Commander Holbrook C Gibson, U S N[1]

Shortly after the armistice, the author witnessed the surrender of the German submarine fleet and subsequently inspected 40 of the 170 submarines first surrendered. He also inspected 185 submarines in Germany. Practically all the engines were of the Machinenfabrik Ausburg-Nürnburg four-cycle Diesel type, of 300, 550, 1200 and 1750 hp. There were but five Krupp two-cycle engines. Brief comment is made regarding the design of these engines.

The author, who supervised the dismantling of the German submarine U-117 at the Philadelphia Navy Yard, gives a detailed description of its engines, which were of the 1200-hp. type. This includes comments regarding materials, design details, valve mechanism, starting and reversing gear, lubrication, cooling and accuracy of workmanship. The air-compression system and some of its auxiliaries are outlined.

In conclusion, the author believes that the Diesel engine is not a cheap product and cannot be made cheaply and run with any great success or reliability. He is confident that the Diesel engine is past the experimental stage and that it is a practical proposition.

Shortly after the armistice, I had the good fortune of witnessing the surrender of the German submarine fleet. The most noticeable thing was that the submarines came in maneuvering on their engines. They did not do it theoretically; they did it practically. Following this I was sent on a mission to inspect submarines. I inspected about forty of the 170 German submarines that were at first surrendered. I then went to Germany and inspected the remainder of the German submarine fleet, about 185 vessels; some of them were new and others were in various stages of completion and repair.

We found that practically all of the engines were of the Machinenfabrik Ausburg-Nürnburg four-cycle Diesel type. In the submarine service during and prior to the war, we had always believed that the two-cycle engine was the only type worth-while. The Germans evidently did not share this opinion. We found that there were but five Krupp two-cycle engines, and that all were out

[1]Submarine Repair Base, League Island Navy Yard, Philadelphia.

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of repair. Practically the entire German submarine fleet was equipped with the Machinenfabrik Ausburg-Nürnburg four-cycle Diesel engine, divided into four very distinct classes of 300, 550, 1200 and 1750 hp.

While riding in one of the former German admiral's barges, I noticed that we were going very fast, then that we stopped, backed and went ahead very quickly, much more quickly than in any motor boat I had ever been in before. I found the barge was equipped with a beautiful 100-hp. air-starting Diesel engine. Later, at Hamburg, we found two engines of the 3000-hp. type, with ten cylinders. But they are all of the Machinenfabrik Ausburg-Nürnberg type, and they all have the same fundamental principles; the only difference being that they make certain mechanical changes in the design as the engines increase in horsepower. The 100-hp. and the 300-hp. six-cylinder engines run at 550 r.p.m.; the 550-hp. and the 1200-hp. run at 450 r.p.m. When they jump up to the 1750-hp. engine they cut down the speed to 390 r.p.m. It is a very noticeable fact that they are all six-cylinder engines, with air compressor and spray air injection, except the 3000-hp. engines, which have ten cylinders. They ignore the eight-cylinder unit. There is a reason for jumping from six to ten cylinders. We have a number of eight-cylinder engines on our submarines, and they are giving trouble in some cases.

The Engines of the U-117

We brought back several of the submarines, but not until after all the Allied countries had taken what they wanted, and our boats had been abandoned for six months. The engine hatches had been left open, and the engines were not even drained down. However, we crossed the Atlantic with them and nothing happened.

I have had the good fortune of dismantling the German submarine U-117 at the Philadelphia Navy Yard. We have taken out the engines, which are of the 1200-hp. type, a typical engine which was used more than any other type in the German submarine service. It has six cylinders, with an air-compressor on the forward end.

To my mind the submarine Diesel engine is a special breed. It bears the same relation to the Diesel engine industry as the aviation engine bears to the gas-engine industry. It must be an engine with the greatest strength, of the lightest weight, and must stand the most severe

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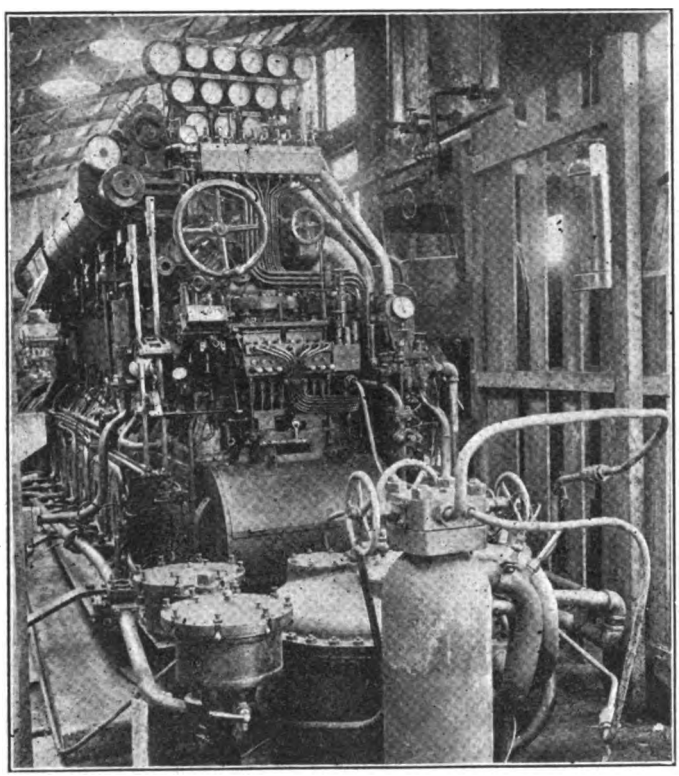
treatment; most important of all, it must be reliable and accessible; it must be everything that it is difficult for an engine to be. The Germans have done things that we have not done. They have overcome certain difficulties that were bothering us. We were getting along fairly well, but they were getting along somewhat better. Any country which staked its all on a submarine campaign must have had some good ideas to start with. The Germans made some very beautiful castings; they are really remarkable; light, clean, and made of steel. Everyone who looks at the castings admires them.

The six-cylinder engine is made in three sections. Instead of being bolted on the flange, the bedplate comes right up and forms what might be termed the housing; the bedplate and housing are integral and thoroughly



THE ENGINE OF THE U-117 AS IT APPEARED AFTER BEING REMOVED FROM THE SUBMARINE AND SET UP FOR TESTING

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ribbed. The sides of the cylinders come down and are bolted to each other. The cylinder jackets come out in a skirt, and that skirt gives the vertical structure and strength. With this casting and cylinder jackets bolted together, a very rigid construction is obtained, but one that is very light, comparatively speaking; lighter than cast-iron construction. The engines have a one-piece crankshaft, with six throws, and two throws for an air-compressor on the forward end. The workmanship is excellent. We put calipers on the main bearings and on the crankpins, and we could find no difference down to 0.0001 in. The usual connecting-rod construction is used with an eye in the upper end for the wrist-pin. This engine runs at 450 r.p.m. and has a 16½-in. stroke, so the piston speed is very high.

We tested the cylinders with calipers and they are all round after running some 40,000 miles, which is very remarkable. The pistons have five piston-rings, and the pistons taper gradually from the top to the bottom working ring. The piston, which is 17¾ in. in diameter, is run with 0.010 and 0.014-in. clearance. The wrist-pin bearing runs at 0.004-in. clearance, which also is remarkable. The usual practice in this country is to put an ordinary shell or bushing in the eye of the connecting-rod. It is sometimes of babbitt and sometimes of bronze, and comparatively narrow; it does not extend out to any distance on the sides of the connecting-rod. The pressure is very high, and incidentally it is very warm in there. The Germans circumvented any difficulty in that place by putting in a steel shell or cap, which might be called a steel support; it is double the width of the connecting-rod. In other words, they took the extreme width of the piston inside, as much as they could, and made it a wrist-pin bearing. That wrist-pin bearing is babbitt and, for some reason which I do not know, the wrist-pin is hard. In other words, the construction is practically the same as in an ordinary crankshaft bearing with a hardened pin. It is absolutely smooth and round and straight. To show how these wrist-pin bearings can take care of the excessive pressures, when we dismantled this engine we found that two of the cylinders were badly scored. We traced this back to the fact that when this boat was surrendered the muffler stop valves had been left open and the rain water had rusted two cylinders. At the time we knew nothing about that, but started the engine and ran home on it. Also, one air-compressor cylinder

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was so badly scored that the lower end was streaked and cracked, but still it ran well. There was no excessive heat, and not a sign of wear on the wrist-pin bearings. In our own engines it is very difficult to ascertain what causes the trouble in case of a piston seizure; whether the wrist-pin or the piston grabs first and causes the wrist-pin to seize.

In this Diesel engine we found that one of our greatest troubles had been overcome in a simple way. The cylinder heads are round and flat, and about 1 ft. thick. They are plain ordinary castings, with inlet and exhaust valves diametrically opposite on the center line of the engine, an air starting valve, a relief valve and a two-spray valve. The two-spray valve construction is carried out in all their engines, from the 550-hp. size up. I have been asked the reason for the two-spray valves. There are several good reasons. They have the exhaust valve and the inlet valve as large as possible. There are two round holes in the head and a round cylinder. If those holes are brought together there is no place for a spray valve, and if the valve holes are made small enough to get a spray valve in between, the whole head is weakened. So, when they needed great power, they used the two-spray valves. The two-spray valve construction works very well and a very good atomization of fuel is obtained.

It has been asked how they manage to make both spray valves lift at the same time; that is, so that one does not lift without the other, and so cause irregular firing. This is simple when explained but consists of several steps. What they have is a cross; it might be called a crosshead guide, which goes up in the middle to lift the two valve-stems. Where the crosshead guide takes on the valve-stem, they have a self-aligning bearing or dished washers. When the valve is being set, one valve is lined up first and then the other valve is lined up to it. Inside of the valves there is a distance washer which is accurate to 0.0001 in. so as to get the exact lift on each valve. There is no trouble if the valves are properly lined up; they work exactly like one valve, and can hardly be considered in any other way.

The engine is air-starting and reversing, but it is reversed by raising the valve gear off the head, clear of the camshaft; the next part of the operation is the translation of the camshaft and the last part the lowering of the valve gear to normal position so that the cam

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rollers fall on another set of cams. That is ordinary construction. There is nothing very remarkable about it, except that it is carried out very well. The reverse can be actuated in 4 or 5 sec., or just as fast as the wheel can be worked.

The cylinders are connected in series, with two levers, and when both levers are pulled back the air is admitted to all six cylinders. They are connected up straight through the heads. When the engine attains sufficient speed, as after several revolutions, one lever is shoved over to the running position; when three cylinders pick up the firing, the other lever is shoved over to the running position. The engine starts from being entirely cold, with no trouble.

The engine is remarkable in its maneuvering qualities. We put one on a test stand to make certain tests required by the Bureau of Steam Engineering for minimum horsepower. The minimum horsepower of this engine is just sufficient to turn it over; that is, to overcome the engine friction. It will run with perfect combustion, delivering no load at the flywheel. By perfect combustion I mean that the temperature is not excessive, and the exhaust is absolutely invisible.

Workmanship

The workmanship on the engine shows exacting care throughout. It is a wonderful example of thoroughness. Every thousandth of an inch is accounted for. Everything about the engine shows that it is put together scientifically, and for a reason. And, above all, it is put together well. One of the foremost engineers in this country on Diesel engines looked over this engine and admitted that there were several very fine things about it, but said that such workmanship is very expensive; and so it is. For instance, the piston is an ordinary cast-iron piston except for the workmanship on it. Every ring fits exactly. The top working ring has 0.008-in. clearance and the next ones 0.006, 0.003 and 0.002-in. clearance respectively. The working rings are all lap-jointed. Each ring is secured by a dowel pin. The bottom working ring is an oil-wiper, and at the bottom of the piston also there is an oil-wiper. That oil-wiper looks the same as the other rings, except that the upper part of the ring is beveled off; the lower part is like an ordinary working ring. The confidential instructions we managed to obtain show that when this wiper-ring

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wears to one-half the width of the ring, it should be renewed.

The lubrication of this piston has been a source of many questions and many arguments among persons interested in lubrication. The only lubrication that the piston gets is from the splash, and there are the two very efficient wiper-rings to take off any oil that gets up there. In addition, there is an auxiliary lubrication system which is taken from the main-bearing supply. This consists of a manually-operated spring-valve, one for each working cylinder. By pressing down on these little valves, one for each working cylinder, oil is squirted into the cylinder. We figured out that this oil makes contact at about 3 or 4 in. above the bottom wiper-ring when the piston is on the bottom stroke; on the top stroke it shoots right into the crankcase. The instructions read to squirt oil on the piston about every ½ hr.; that is all the lubrication that the piston gets and that is why it does not carbonize.

It is all a question of workmanship. With a round piston and a round cylinder, the friction is eliminated to a very large extent. To illustrate this, one man with a 2-ft. bar can jack the engine over with one hand. Everything is exact.

In some of our large engines in this country, getting oil up into the wrist-pin is one of the great problems. The connecting-rod is naturally hollowed out to reduce the inertia forces and to make it lighter. When that big rod becomes filled with oil, the inertia forces acting on the oil have a tendency to take the oil away from the wrist-pin. To overcome this tendency, some of our engines have what we call a foot-valve or check-valve, in the foot of the rod; this is very hard to remove in case it sticks or chokes, particularly at sea. The Germans have hollowed out the connecting-rod and simply put an ordinary plug into the bottom of the connecting-rod and run a pipe up to the wrist-pin, instead of forcing the whole connecting-rod full of oil and letting it ooze out to the wrist-pin.

The pistons are oil-cooled. The lubricating oil and piston-cooling oil all return to a sump tank and are pumped from the sump tank through a cooler; from the bottom of the cooler the oil goes to the main bearings. Another pipe comes from the top of the cooler, and this leads to the piston cooling system.

The pressure delivered to the cooler is about 60 lb. per

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sq. in., but by the time it gets through the cooler and to the bearings it is reduced to about 30 to 40 lb. per sq. in.

There is an automatic regulator on the forward end of the engine so that just the right pressure and quantity are delivered to the main bearings; all the remainder goes to the piston-cooling system. Thermometers are provided so that it can be seen that the piston-cooling circulation is not restricted, which is very important for marine use. At sea it is necessary to know if there is salt water in the lubricating oil, because this causes trouble with the piston-cooling system.

Air Compression

The 550-hp. and larger engines all have the four-stage air-compressors; that is, on this engine there are two cylinders of the first stage, two of the second, one of the third and one of the fourth; the pistons are exactly the same, except that one has a third stage and the other a fourth. That, also, is run very close. They take great care that each stage is fitted with a separator and a cooler. It is the practice to blow down every 15 min. to remove any water or oil in the air. The engine exhausts into what is called a dry muffler. No water is put into the muffler to make it silent, or to keep it cool. The muffler is of course water-jacketed.

The Germans were obviously short of material and did things on the engine which I suppose were done through necessity. They have done things with steel piping which we do not yet know how to do. All their piping is of steel, with the exception of a few gage lines. Even the spray air lines are of very small pipe made of steel. All over the engine there are very fine examples of the welding of steel plates and pipes. The entire exhaust header, which is water-jacketed, is made of very thin plate welded. It weighs about 1200 lb. for this size of engine, which is very light.

The engine has also a very unique device on its forward end, called a spray air regulator. The spray air is regulated automatically for the horsepower or load that is being developed; the more horsepower the engine develops the higher the spray air. The Germans use their engine air compressors for pumping up the ship's tanks; they can pump up to 3000 lb. When we looked at the engine, we agreed that we did not like the arrange-

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ment of the compressor. The air-compressor valves in some of the stages are not very accessible.

SUMMARY

The Diesel engine is not a cheap product and cannot be made cheaply. Perhaps it can be made cheaply and sold; but it cannot be made cheaply and run with any great success or reliability. It all depends on what they are being used for. A high-grade engine must be well made, and the material in it must be as near perfect as possible. The engineer and the metallurgist must cooperate in this.

The Germans are not yet satisfied with their engine. We had evidence all through the German submarines that they are still experimenting. We find slight differences in the mechanical details. They are trying all the time to perfect what they already have, which is very reliable, comparatively speaking.

Regarding our own engines, we have something yet to learn. But to build a Diesel engine costs money. The German Diesel-engine builders were backed by the German Empire. They have a good design; we are now trying to take the good points from it and adapt them to our own use. We do not say that what we have is all wrong, because it is not. We may approach the problem in an entirely different way, but it is well to take the good points they have and by adding those we have we ought to go them one better. That is what we are trying to do.

We are in difficulties in this country on account of patents. We have several companies building Diesel engines and competing with one another. It is all right when building automobiles to do private research work and guard the secrets very carefully, but the submarine Diesel engine is one for which there is no demand in the commercial market.

The logical way of going into the problem of developing a real submarine Diesel engine is either for the Government to do it or back the Diesel engineers of the country in research work, with that primary object in view. I am confident that the Diesel engine is past the experimental stage. I have seen Diesel engines of 100 to 1750 hp. in operation. The Diesel engine is a practical proposition.

THE DISCUSSION

CHAIRMAN JOSEPH VAN BLERCK:—Is my understanding correct that the oiling system is a pressure system on the main bearings?

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COMMANDER H. C. GIBSON:—Yes; the pressure is about two atmospheres.

CHAIRMAN VAN BLERCK:—Is their reason for having the babbitt in the wrist-pin to cut down the friction, reduce the heat and keep the wrist-pin from wearing flat?

COMMANDER GIBSON:—I can understand the babbitt, but I do not understand why the wrist-pin should be case-hardened with a babbitt bushing.

CHAIRMAN VAN BLERCK:—The case-hardened bearing is always better, according to my experience. If we could have case-hardened crankshafts today we would accomplish something. With tractor and truck engines, where there is dust to contend with, the only serious difficulty is the wearing of the crankshaft. An engine which has been subjected to dust, when taken apart shows everything else perfect; the piston-rings and babbitt bearings have not become worn, but the crankshaft is worn flat. That is the first place to look for trouble when there has been any dust in the engine.

COMMANDER GIBSON:—The usual practice I have seen in wrist-pin bearings is to have a bronze bearing in the connecting-rod.

ERWIN CHASE:—Do the Germans consider that there is any future in the two-cycle Diesel engine for submarine use, or have they abandoned it entirely?

COMMANDER GIBSON:—Several German submarine officers have said that they have no use for them, because there is always danger of getting salt water into the piston-cooling oil which in a two-cycle engine is very serious on account of the heat. Because there is so much heat to dissipate, the coolers and pumps must be much larger than in a four-cycle engine. They favor the four-cycle type. In fact, many of the European countries are building four-cycle engines. For submarine use, I favor the four-cycle type.

H. C. GIBSON:—Diesel engines, like all other engines, are needed for the work they will do and, if a properly constructed Diesel engine will work without trouble, 10 to 20 per cent more spent in the initial cost of that engine is more than paid for in its economy of operation and decreased depreciation. It is most serious that we should at any time consider that we must subordinate accuracy of workmanship in commercial engines. The subordination of accuracy of workmanship to price alone is not the proper basis upon which to construct any piece of mech-

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anism, especially a complicated, difficult piece of mechanism subject to such high stresses.

COMMANDER GIBSON:—I agree with that. With an engine that will run without any trouble and reach port not only once but several times, the confidence of the crew has been gained and they will swear by the engine. They will then understand that if little things happen they are merely incidental, and that such things will happen to almost any engine. Confidence in an engine is a thing to be cultivated. The commercial engine, as well as the marine engine, must be reliable. Reliability requires good workmanship and design. Good design and good workmanship go together.

A MEMBER:—I can say from experience that we need better workmanship. As an instance, on a ship with a new engine the engineer was suspicious of the engine because of the finish and the way the connecting-rod bearings were fitted. His suspicions were correct; the engine was out of line. That shows the need of good workmanship.

A. M. WOLF:—At our December meeting we had an interesting paper on the Torsional Vibration of Crankshafts, in regard to the Diesel engines employed on our submarines. In view of the difficulties we have had, what has been Commander Gibson's experience regarding the vibration encountered in the German Diesel engines? What speed did he find to be the critical one, and what was the extent of the vibration?

COMMANDER GIBSON:—I cannot state the figure offhand, but the engine is very sensitive in regard to critical speed. There is a certain spot at which the vibration is very noticeable, which is evident just the minute it occurs; but below or beyond it the engine is as steady as a rock. The minute the critical speed is reached the engine makes a tremendous racket. So, we give it more fuel or regulate the engine as the speed is increased or decreased.

CHAIRMAN VAN BLERCK:—In regard to the workmanship on the German engines, I think we would have no difficulty in getting even better workmanship if the Navy Department, for instance, built one good engine and then put a thousand of those engines through the shop all at once. That would guarantee better workmanship than the Germans ever had. I think it is not the right idea to build one engine today and six months from now another.

A MEMBER:—Has Commander Gibson any thought on

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the solid injection as compared with the air-injection system?

COMMANDER GIBSON:—All the German engineers continue to use the spray air. The Vickers people in England use the solid-injection system. I believe the solid-injection system will come, but it gives poorer maneuvering qualities to the engine at present, in comparison with spray air. The German engines, in addition to their spray air regulators which give certain definite spray air for certain speeds and loads, have a control on their spray valves which allows a spray valve to lift a certain definite distance, according to the amount of the fuel to be delivered to the engine; the more the fuel required, the greater the lift is. The problem is involved with the spray-valve control. It is very unique, and it works beautifully. The engine can be shut down to low power with very little fuel and very little lift of the valve and complete combustion is obtained. I think that could not be done at present in the solid-injection system.

G. F. CROUCH:—By whom was this engine produced?

COMMANDER GIBSON:—The German submarines revealed the fact that although it was a Machinenfabrik Ausburg-Nürnburg engine, originally built in Ausburg, the engine was farmed out to every Diesel engineering company in Germany.

C. F. SCOTT:—How does the fuel economy compare with that of the lower-speed types.

COMMANDER GIBSON:—The economy is very good. About 0.42 lb. per b.hp.-hr. is obtained at full power. That is not remarkable; it is good, and the combustion is good. We use every bit of the fuel in the cylinder. We ran a test generating 35 hp., just enough to overcome the friction loss of the engine. We had 35 hp. on the load, and we used 35 lb. of fuel. do not know how it compares with the marine type engines that have been built for use in private vessels.

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ADAPTING TRUCK AND TRACTOR ENGINES TO MOTOR-BOAT USE

By Joseph Van Blerck[1]

The automobile engine, as used in passenger cars and a large percentage of trucks, is not adapted to use in motor boats. It is not built substantially enough for this, inasmuch as the power output of the motor-boat engine, except during starting or landing, is always 100 per cent. In view of this and because tractor, truck and marine engines are of the same family, it appears that if a truck or tractor engine were made with 100 per cent continuous power output capacity it would be satisfactory for marine use.

The author describes and illustrates a tractor engine modified for marine use. The lubrication system of this engine is explained. The respective merits of right and left-hand engines are discussed. It is stated in a twin-screw boat that it is unnecessary to have both engines run out-board; that both can turn in the same direction without causing material difference in results. The sliding reverse gear used in connection with the marine engine described is illustrated and its merits enumerated.

The automobile engine, as used in passenger cars and a large percentage of trucks, is not adapted to use in motor boats, and is not built substantially enough, since the power output of the motor-boat engine, except when starting or landing, is always 100 per cent. In view of this and because tractor, truck and marine engines are of the same family, it would appear that if a truck and tractor engine were made for 100 per cent power output, we would then have a combination which would answer these three purposes. The marine engine must be capable of running under full load for an indefinite time at a 12 to 15-deg. incline. It was found that nothing satisfactory could be evolved from the old-time plan of building engines; we therefore awaited an opportunity whereby the marine engine could have the advantages of large production. These

[1]Manager, motor division, Wellman-Seaver-Morgan Co., Akron, Ohio.

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advantages are many; the difficulties encountered in the small shop of low production are obvious.

Fig. 1 shows a tractor engine. It has a fan driven by a gear, a governor on the engine and an oil sump. The oil-pump is in the center of the sump to provide adequate oiling at either an up-hill or down-hill angle. A reversing gear is attached to the engine. The fan and governor are separate units and can be attached or detached at will. The flywheel is in the rear of the engine, with the clutch located within the flywheel; the power is thus transmitted through the flywheel. This is the only proper way to transmit the power. Difficulties have always been encountered, and marine engines have been designed to suit boat builders and naval architects. The result has been that flywheels have been installed at the front part of the engine. Some marine engines have, however, been built with the flywheel in the rear, but this was only in the case of heavy-duty engines for large boats and it was claimed to be impossible to install such engines in small cruisers or runabouts.

I have made a slightly different oil sump. The flywheel is smaller and allows for dropping the engine closer to the keel. This is being done to avoid criticism and to get the engine into boats which are already built, but I am satisfied that there is no need of having this oil sump when designing a new boat. I hope to receive sufficient support from naval architects and motor-boat engineers, so that within a short time this oil sump will not be required and we shall be able to use the deep oil sump, thereby making the entire assembly standard. The reason for making the deep oil sump is that, on account of using the engine for cruisers, a heavy flywheel is desirable. However, we must eventually make two kinds of flywheels to answer these two purposes, as the runabout engine for high speeds does not require such a heavy flywheel. We use the same supporting arms that are used on the tractor engine, except that we have made two foundation plates for bringing them to the center of the shaft. This would be unnecessary except that it is easier for a boat builder to build the foundation on the center line of the shaft. Concerning the engine supports, if these are sufficient for the engine in a tractor or a truck, they will support the marine engine, which must withstand certain shocks but nothing like as severe as those of tractor and truck service.

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Right and Left-Hand Engines

We have been building right and left-hand engines, which means that for a twin-screw boat both engines must run out-board. We have discovered from past experience that it is unnecessary to have both engines run-

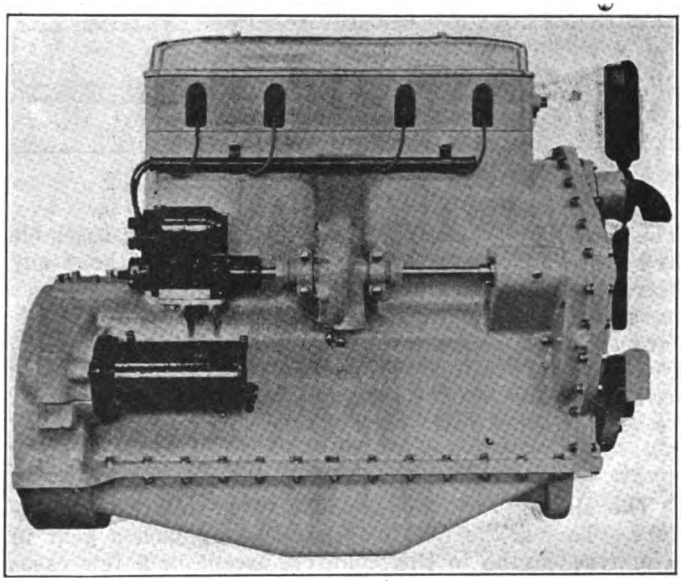

Fig. 1—A Tractor Engine

ning out-board; in other words, both engines can run the same way and there will be no difference noticed. We are well on the way to attaining this point. Several boat builders are working on twin installations and planning to have both engines run the same way; in other words, they will use two standard engines. To make engines run in opposite directions we must change the rotation of the oil-pump, magneto, water-pump, generator and starting pump; it also necessitates a different camshaft. Our oil and water-pumps are made so that they can be run either way at will; but it costs more to do this, as parts for these pumps must be kept on hand.

Fig. 2 shows the camshaft. It is made in such a way that it can be used for a left-hand camshaft by cutting off the bearing and flange on one end and reducing the

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shaft to the same size as the opposite end; then making a separate bearing, coupling and key in this end. The necessity of asking camshaft manufacturers to make left-hand camshafts is thus obviated. Fig. 3 shows the marine engine with the centrifugal pump taken off and a gear pump installed in its place. The centrifugal pump is unsatisfactory because of its inability to suck water.

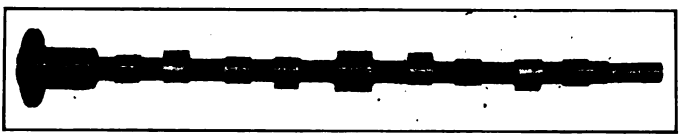

FIG. 2—THE CAMSHAFT OF THE TRACTOR ENGINE

The gear pumps are made so that we can disassemble and reassemble them for left-hand pumps without any extra machine work. We hope ultimately to convince naval architects and boat builders that it makes no difference in small boats which way the engines are running. Fig. 4 is a view of the engine from the opposite or carbureter side.

SLIDING REVERSE GEAR

The sliding reverse gear is another interesting feature. This is the first incorporation of such a gear in a marine engine in this country, except in a few cases where an automobile engine has been used in a motor boat and the automobile transmission has been used. This use has, however, never been successful, due to the fact that the reverse ratio is too low in the automobile transmission. Our reverse gear has an 82 per cent reverse and this can easily be made a 1 to 1 reverse. The reverse gear has been tried out under both normal and abnormal boating conditions and has given absolute satisfaction. I firmly believe that this is the only practical way known for reversing a propeller. The gears used in this reverse gear are now manufactured in shops where they make transmission gears and advantage can thus be taken of the experience of the transmission gear manufacturers, insuring the making of a first-class gear. The gears are made along the same lines as the transmission gears for cars and trucks, of nickel steel, case-hardened and ground. Fig. 5 shows the gears as they are assembled in the housing. I will outline a few of

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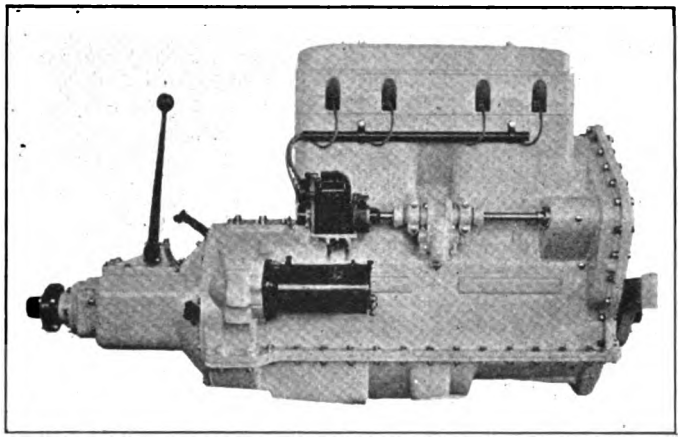

FIG. 3—A SIDE VIEW OF THE MARINE ENGINE IN WHICH THE CENTRIFUGAL PUMP HAS BEEN REPLACED BY ONE HAVING A GEAR DRIVE

the things that can be done with this reversing gear. When the lever is in the neutral position, with the engine running, the propeller-shaft can be turned by hand in the opposite direction because it is entirely separate from the engine. Therefore, a perfect neutral is obtained. Considerably less power is thrown on the engine when reversing than when in the go-ahead position. In other words, when the engine is running in an idle posi-

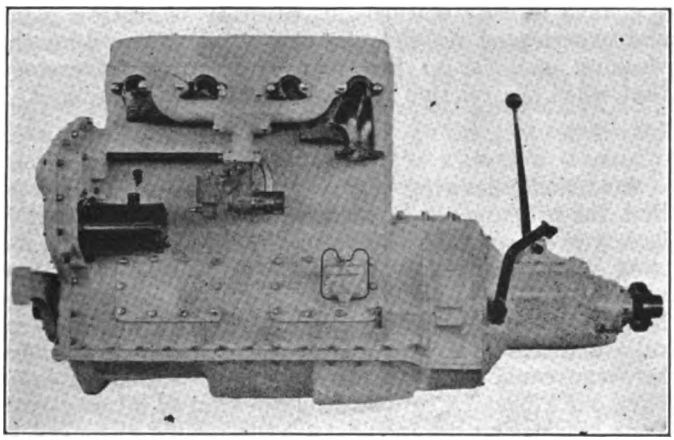

FIG. 4—LOOKING AT THE ENGINE FROM THE CARBURETER SIDE

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tion and is then thrown into the reverse, there is absolutely no danger of stalling the engine. When the boat is going at full speed, if the occasion arises to reverse at once the first thing is to throttle the engine. The engine will then act as a brake to retard the speed of the propeller-shaft, say down to about 300 to 400 r.p.m., which is the required speed for shifting the gears. Between the time of shifting from the forward into the reverse position, the propeller has no chance to pick up speed through the momentum of the boat. This gear can be shifted from the forward to the reverse position just as fast as it is possible to shift from first into second speed on an automobile.

In the case of the twin-screw boat, the propeller of the dead engine is free to revolve in the water; it therefore does not retard the speed of the boat because there is one short shaft revolving which runs on two ball bearings. This is a great advantage in an auxiliary yacht which depends upon having the propeller running freely in the water while under sail. It will be appreciated what the drawback has been in the past and to what extent this reversing gear will remedy the condition. In regard to connecting the clutch and gearshift in different places in the cruiser, this can be accomplished much more easily than with any other kind of clutch because it works only one way. It can be worked with a cable and pulleys if necessary. Relative to the gearshift lever, this does not require any strength to operate; it can be operated by small connecting-rods and levers. We have already worked out several installation plans and experienced no difficulty whatever. Regarding the wearing qualities of the gear, it is easily understood that when the friction is reduced the wear is reduced.

Lubrication

A sectional drawing of the tractor engine would show that the oil-pump is in the center of the sump, that it is driven by spur gears from the main timing-gears and runs slightly faster than crankshaft speed. The oiling system has been given very careful attention. Very heavy oil can be used in this engine with excellent results and also the thinnest oil obtainable; in fact, pure kerosene could be used and it would be impossible to burn out a bearing as long as some kind of oil was used. Poor lubricating oil does not do the engine any good in the long run and the use of it will reduce the life of the

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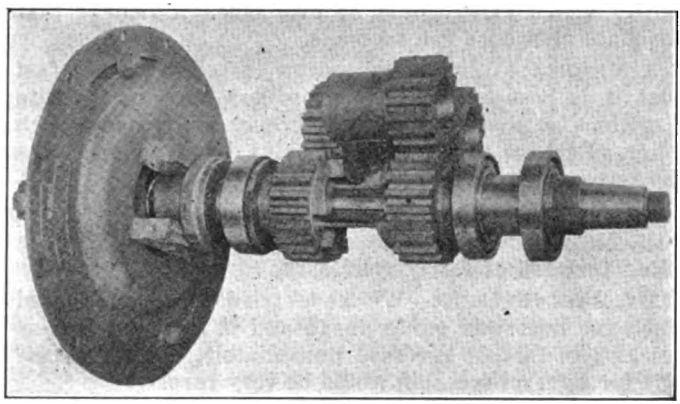

FIG. 5—SLIDING REVERSE GEAR

engine, but that is different from burning out bearings and ruining the engine. Past experience shows that there is little use in recommending a certain kind of oil for use in an engine; the owner cannot at all times obtain the oil he wishes and is therefore forced to use what he can get.

THE DISCUSSION

A MEMBER:—If it is desired to run propellers in opposite directions and to build only one-hand engines, why cannot one engine be run through the reverse to go forward and in the forward position to reverse?

MR. VAN BLERCK:—It would not be desirable to transmit the power through the reverse continuously. The power would be transmitted through the gears and would not allow quiet running. There is a certain amount of friction also to be avoided. There is a probable loss of 5 per cent through the gears.

A MEMBER:—It is well known to every boat builder and boat handler that, if a twin-screw boat in which both engines turn in the same direction is allowed to run with the rudder free, it will invariably turn to one side. It is a fundamental law of physics that cannot be overcome.

MR. VAN BLERCK:—If engine manufacturers were to build no left-hand engines for running propellers in opposite directions it would not be long before any diffi-

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culties which exist would be overcome. I believe that adequate allowance can be made.

A MEMBER:—With a twin-screw installation on a fast boat it is best to have the propellers turn in opposite directions so that the opposed torques will balance each other. Perhaps this is a minor point, but it exists. Has the reverse gear been tried out?

MR. VAN BLERCK:—Yes.

A MEMBER:—I refer to checking the boat when it is going forward at fairly good speed?

MR. VAN BLERCK:—We have tried it at full speed when the boat was going ahead and it reversed just as quickly; in fact, it reversed immediately, but the necessity for such an occasion would be very rare.

G. F. CROUCH:—I recall an instance of this necessity. While in a small boat, a piece of driftwood locked the rudder; the boat started straight for a dock. Fortunately, we hit one of the piles on the side; otherwise we would surely have gone under the dock. The boat had no reverse gear.

MR. VAN BLERCK:—If two boats, one without a reverse gear and one with a reverse gear, were both run for a dock at full speed and then shut off to try to reverse at a certain distance from the dock, the boat without a reverse gear would be in the more dangerous situation.

MR. CROUCH:—The reverse gear is a decided improvement on the conventional type. A friend of mine found that he could not reverse until his boat had practically lost all forward motion. He then put a brake-band on the propeller-shaft.

MR. VAN BLERCK:—We did that in the first try-out; it worked well. Then we took the brake-band off and it worked just as well. So, why put on a brake-band?

ERWIN CHASE:—I accompanied Mr. Van Blerck on the trials he mentioned and no one could require more of a reverse gear than he did. From going full speed ahead he went into full speed reverse and never missed. He had a brake-band on the shaft, but it was not necessary to use it. That was not a very fast boat; with a high-speed boat, in which the propeller-shaft runs very freely, it might be necessary to have a brake-band.

With both engines running the same way in a twin-screw installation, if both were right-hand wheels, the engine on the port side, having an arm from the center line of the boat to the center of the resistance of the boat,

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would counteract the arm of the engine on the other side.

MR. VAN BLERCK:—In regard to higher-speed boats, no matter how fast the engine is running, all that is necessary is to close the throttle; an engine will slow down quickly when it has no gas. When the propeller slows down to engine speed, then is the time to reverse. But with the high-speed boat, if the clutch is thrown out and the reversal not made at once, the propeller will gain speed and there may be some difficulty.

H. C. GIBSON:—I had a boat 51 ft. long with 16-ft. beam; the engine was installed in a way similar to that in which an engine is installed in an automobile. We sat alongside the wheel and operated the clutch by foot power. We had the usual H gearshift arrangement. I used that boat for several years and it was always perfectly satisfactory. I never had any difficulty in picking up any of the gears, whether the engine was running fast on low gear or slow on high gear. I could make any change I wanted to make. That was a rather strenuous test, for the propeller was 36 in. in diameter.

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NEW YORK AERONAUTIC MEETING

Vice-President Glenn L. Martin presided at the professional session held on the afternoon of March 10. Major V. E. Clark outlined a paper he had prepared on Possible Airplane Performance with Maintenance of Engine Power at All Altitudes. He also showed some moving picture films of recent engineering work at McCook Field, the particular items of interest referring to devices for dropping the wheels from a plane when in the air and for inflating air bags for the purpose of absorbing a portion of the shock when landing on water; examples of dropping bombs separately and in unison; and parachute work. Interesting points were elucidated concerning the recent ascent of Major Schroeder to 36,000 ft. in a LePere plane driven by a Liberty engine equipped with a Moss supercharger. It was stated that on account of rarification of the atmosphere at such great altitudes the carbon monoxide in the engine exhaust becomes so diffused as to be harmful and dangerous to the pilot and that under such conditions arrangements will have to be made to carry the exhaust gases well away from the pilot. The reported temperature was — 67 deg. fahr., one result of this being the formation of the exhaust into a comet-like icicle of astounding length.

As was stated by Vice-president Martin, the papers presented showed that marked progress has been made recently in aeronautic engineering. Grover C. Loening, in a paper entitled Effect of the General Shape of Aviation Engines on the Operation of Airplanes, gave some very interesting data on the power developed by and the air resistance involved in the use of aeronautic engines currently made. His purpose was to analyze the conditions requisite for an airplane speed of 200 m.p.h.

Alexander Klemin gave an enlightening exposition of his subject, Consideration of Landing Run and Getaway by Standard Type Airplanes. Archibald Black presented a brief statement on matters demanding attention in the heat-treating of brazed fittings. S. R. Parsons and S. W. Sparrow, of the Bureau of Standards addressed the members, the former on Factors in the Design of Airplane Radiators, and the latter on

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Flying an Aviation Engine on the Ground. Mr. Parsons' data were constituted of some results of tests that had been conducted at Washington. Mr. Sparrow told of the many advantages of testing engines in a laboratory such as that installed at the Bureau of Standards, wherein conditions of atmosphere and temperature like those at great altitude can be maintained.

The meeting was concluded by a dinner at the Hotel Astor. The speakers were President Vincent, who talked on general development of aeronautics with particular reference to the Air Mail Service; Major-General C. T. Menoher, chief of the Air Service, who presented some interesting facts and figures as to the present status of military aeronautics and advocated the maintenance of separate Air Services for the Army and the Navy; Air Commodore L. E. O. Charlton, formerly military attaché of the British Air Service; Col. Thurman H. Bane, chief of the Engineering Division, Air Service, who pointed out that a National Defense Department could very well care for the operation and maintenance of all Government aircraft and spoke very hopefully regarding the anticipated use of aircraft on a large scale; Past Vice-president George H. Houston, who traced the development of commercial air flight in America and emphasized the necessity of the Government maintaining a properly equipped organization for testing out new designs and doing whatever is necessary to establish the science of aerodynamics on a sound basis, the actual designing being undertaken by civilian organizations; and Major Maurice Connolly who stated that the aircraft sales departments could do much to facilitate the establishment of needed landing fields by presenting concrete statements of the amount of expected business.

ADDRESS OF PRESIDENT J G VINCENT

I am more than ever convinced that our membership as a whole does not thoroughly appreciate either its opportunities or responsibilities. In 1911 we were all proud of our Society and its success, but I doubt if many of us realize that we then had only about 600 members. The membership has since increased rapidly, in a constantly upward curve; in 1912 it had passed the thousand mark; in 1913 it reached 1500; and at the beginning of the great war it was about 2000. It hardly seems possible that the Society was relatively so small

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at that time. Its continued steady growth, its ever-increasing activities and its greater and greater professional and financial success during the war are well worthy of note. We all know that the reason is the essentially important character of the automotive industry and its engineers.

In 1918 there were about 3000 members and in 1919 approximately 4000. The curve is tending in a very satisfactory direction and we now have well over 4500 members. These figures include individuals, companies and their representatives and enrolled students. High-grade representative members are being constantly added and our officers are frequently surprised at the number and character of applications received and the possibilities of additional high-grade membership which are constantly developing. This is a picture that we can all be proud of, but let us not forget that this membership comes about through added activities, each in turn carrying with it tremendously important new responsibilities. It is constantly borne in upon us that we are in the midst of greater and greater things.

The Function of the Society

The basic function of the Society is to reduce costs to the producer and to the consumer and make feasible better products. It has made a record as an engineering organization second to none. The world has seen no more admirable and effective example of cooperation than that of the automotive engineers. It was their cooperative effort instituted fifteen years ago that placed the American automobile in its high rank among the products of the world. The standardization achievements of these men have been based on thorough study, merit and common sense from the start. Greater economy and speed of production of high-class automotive vehicles of many kinds now well known have resulted from their broad and intelligent procedure. The specific things done to this end are too numerous to mention.

The modern use of automobiles and much other automotive apparatus would not be possible if the far-sighted automotive engineers had not promulgated and reduced to almost universal practice many standards. The Society has established over 200 distinct mechanical and material standard specifications, of mounting dimensions, accessories and the like, and the work has only begun. The American automotive engineers have been the pro-

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genitors of the world-wide standardization movement now very plainly recognized. Standardization is a wise simplification of details and is vitally important to international trade. This is appreciated keenly by those manufacturing countries throughout the world now striving to control the key industries.

With such a splendid record of achievement during the war, the Society is now hard at work on many pressing problems. How are aircraft production facilities to be utilized commercially? How is the problem of the more efficient use of fuel to be met to conserve the limited supply? How is the need for a greater and ever-increasing supply of food to be faced in view of the shortage of labor? How is the distribution of food and other commodities, to communities distant from the railroads, to be accomplished? How can automotive engineers contribute to the successful solution of these problems so that this country shall become the successful competitor it should be in the markets of the world? How can lighter, more efficient and less expensive automotive apparatus be produced?

These are all questions in which the automotive engineer has a vital interest and which he must answer; there are many others of like nature. The stimulation of research in new fields will have no small bearing in contributing to the desired results. These are exactly the things for which the Society stands.

We are all keenly interested in the development of aeronautics because it is of vital interest to our country, forming as it does the basis of preparedness in the air. I think everyone will agree that we must never again allow this country to get into the relative position it occupied in aeronautics in the early part of 1917. The solution of these problems very largely depends upon the automotive engineers, but we must take care that we analyze the problems step by step and make sure of our recommendations. To carry on this work intelligently, we must keep constantly in touch with every phase of the situation. I personally believe that the final answer to thorough preparedness in the air lies in commercial aviation, but at best it will be some time before aviation can be put upon a commercial basis. In the meantime we must very largely depend upon Government activities to keep us prepared and as automotive engineers we should give maximum cooperation to Government officials to help them obtain the greatest possible value for

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every dollar spent on aviation, as measured in terms of preparedness. Our cooperation will be of direct value in proportion to how well we are posted and how well we understand the problems faced by Government aircraft officials. Thorough cooperation can be brought about only by a complete understanding of each others' problems. The only way to learn each others' problems is to become well acquainted and discuss the situation frankly without regard to personal interests.

Aerial Mail Service

I shall discuss briefly the possibilities of our aerial mail service from an engineering and production point of view. What we all desire is to be reasonably well prepared in the air for possible emergencies. What is the best way to accomplish this result? Anything that will promote the use of airplanes and thereby develop the art and make airplanes available, will be along the right lines. During the next few years, at least, such development must be brought about under Government direction and with Government funds to a large extent. The Government must therefore determine the best way to bring this development about. We all know that the most effective way to bring about a development is to have a real use for the article which is to be developed, and the Government has such a use for airplanes in the aerial mail service. Why not develop this service in a whole-hearted manner and bring about the results that will be bound to occur, if it is taken seriously and properly extended throughout our country? Such a course of procedure would, in my opinion, bring about the following results:

(1) Airplanes of greatly increased reliability would be evolved, because the planes must fly on schedule time and failure would therefore be brought forcefully to the attention of the proper authorities

(2) Airplanes of greater cruising radius would be evolved, as it is desirable to fly for long distances without landing

(3) The cost of airplanes would be gradually brought down to a proper level, because manufacturers would receive sufficient orders to warrant tooling up

(4) Economical reliable aircraft engines would be developed and as the quantities required would per-

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mit of tooling up, it naturally follows that such engines would be obtainable on short notice at minimum cost. Contrary to popular opinion, these engines could be developed so that they would be equally good for the mail service and for military purposes. Such a development would be of paramount importance, because it takes at least one year to develop an airplane engine and get it into production even under war-time pressure, while the airplane itself can be designed and put into production in less than one-third this time, provided its engine is a known quantity

(5) Many improved instruments for airplanes would be developed, including such important ones as are required for night flying, flying in cloudy weather, etc.

(6) Such a program would gradually increase technical knowledge and develop craftsmen, so that in case of any emergency material for a war-time aircraft organization would be immediately available, instead of losing much technical knowledge and many expert artisans developed during the war, as is now rapidly taking place

(7) There would be a constant demand for good, reliable pilots, so that we would always have a large number of them in training, immediately available in case of an emergency

(8) Such a program, by keeping the aircraft industry alive, would promote the development of commercial aeronautics; this, in turn, would not only hasten the development of the aerial mail service but, what is more important, make available much added technical knowledge and helpful manufacturing facilities for use in case of an emergency

(9) A complete system of good landing fields throughout our country is probably the most important step required to make the development of commercial aeronautics possible. Obviously, the Government cannot be expected to build or maintain such fields, but the expansion of the aerial mail service would, in my opinion, bring about the desired result. These landing fields should be provided by the cities to be served by the aerial mail. I can think of nothing that would stir up so much interest in commercial aeronautics as a system of landing fields throughout this country, with mail planes coming and going regularly every day

(10) In case of emergency, if such a program were in force, we would have a great number of airplanes

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and pilots quickly available to do very valuable service for the Army and to a certain extent for the Navy. It is of course true that the planes would not be military machines, but they could be so constructed, without interfering with their value as mail carriers, that with the addition of some armament which could be very quickly installed they would be very good for observation, photographing and bombing work

(11) A program of this kind would result in the maximum amount of activity and development at minimum cost to the Government, because this work must be done and, by using airplanes to do it, the revenue accruing from such operations would be applied toward the cost of equipment and maintenance

Experience to date indicates that the aerial mail service can be made almost if not entirely self-supporting after being established; but this should not be taken as too important a consideration, for to bring about the results desired it will be important to have sufficient appropriations made to maintain experimental work constantly with a view to improving the equipment from month to month. After considerable thought, I realize more fully the possibilities of bringing about a wonderful development in aeronautics through the use of the aerial mail service as a vast proving organization. I feel sure that if such a program could be made a reality, there would be absolutely no question that the United States would lead the world in aeronautics within a very few years.

When we entered the recent war the Government had no trouble in obtaining prompt delivery of passenger cars and trucks, solely because such vehicles had been thoroughly developed and were in quantity production for other uses. The aerial mail service offers a possibility of bringing about the same condition in aeronautics, by making mail-carrying airplanes and pilots immediately available in cases of emergency and by bringing about the commercial use of airplanes.

ADDRESS OF MAJOR-GENERAL C T MENOHER

I shall present a few facts as to the present status of military aeronautics in this country and a thought or two as to what we may develop for the next war of any

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magnitude. Due to the enforced development in aeronautics during the late war, the science has advanced as far as it would otherwise have advanced in fifty years. Practically all important and lasting progress made by the human race has been by a gradual process of evolution as distinguished from revolution. I regard the advance in the science of aeronautics during the war as in no sense revolutionary, but strictly evolutionary. A comparison of any one of our standard airplanes with the one in which the Wright brothers made their first flight will show that the evolution has been very gradual and along normal lines, the element of time only, that is ordinarily associated with the process of evolution, being in this case very materially shortened. Now that the war is ended and the world is returning to its normal state of being, we can look for a period of normal conservative development in the science of aeronautics.

From the lessons gained in the use of aircraft during the late war, we can anticipate in a measure the part it is likely to play in future wars. It is significant that the industry which produced the aircraft was strictly a development of the war. While it is possible to visualize the possibilities of aircraft, we cannot determine them definitely and can only hope that the industry to produce the aircraft needed for a future war will be in existence contemporaneously with the need. Whether it must be developed as a war-time measure, as was the case in the last war is dependent in large measure upon the success of commercial aeronautics. If aircraft in industrial and governmental usage is proved to be economically successful, the industry which produces the craft will be available for war production. There will be many types of aircraft in operation suitable for some war use and a great personnel having a large part of the necessary knowledge for their operation, which will be a distinct asset. In case, however, of the economic failure of aircraft, the tremendous expense involved in operating an adequate air fleet will necessarily limit the number which can be maintained as a preparation for war.

In future wars, the first arm of defense to come into active operation will be the air service. The relative size of our air force and that of the enemy, and the total number of machines that it will be possible to put into operation immediately after the war begins will determine the character of the preliminary phase of the war. It is entirely possible that one belligerent may have

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sufficient aircraft of adequate size and range of action to drop enough explosive and deadly gases on the centers of government, production and military strength, to end the war almost before it has begun. Certainly it would be possible to hamper and delay the embarkation and transportation of any expeditionary force long enough to enable the aggressive belligerent to make a considerable preparation. In this connection it should be remembered that the sea, which was formerly a barrier, has now become a highway; and that we will have much less time than formerly in which to prepare to resist an invasion. The advent of aircraft has very materially shortened this time.

Since we cannot determine definitely whether commercial aeronautics on a large scale will be successful, and consequently cannot visualize the size of the industry in the future, it is impossible to anticipate the size of an air force that may be thrown against us by any first-class power. It is a military principle, however, to recognize that the initiative and resourcefulness of the enemy are probably as great as our own, and to plan and prepare for meeting the worst situation conceivable. We should keep in mind what might be our situation should aeronautics take the place in our governmental and industrial life that now seems possible, and that a possible enemy may have at his disposal a large air force and the industry necessary to maintain it. With comparatively little advance in the development of the lighter-than-air craft, we must be prepared to attack and destroy dirigibles capable of carrying enough explosives to paralyze our industrial and governmental centers. If we have an adequate air force at our disposal we should be able not only to retaliate but to attack an invading force at his ports of embarkation and to continue the attack on his transports and fleets until our Navy has joined with his. In the naval engagement aircraft will play an important part, not only as an auxiliary to the battleships themselves in fire control, but by actual attack by both heavier and lighter-than-air craft on hostile war vessels themselves. On the approach of the enemy fleet to our coastline, aircraft will cooperate with our coast defense; it will attack during his efforts to disembark and establish a base on our shores; it will cooperate with our land forces after the establishment of his base; and it will continue to attack his transports and ports of embarkation, and even his depots and munition plants, throughout the war.

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Aircraft in War

The two general classes of use of aircraft in war are first, by the Army and Navy in direct cooperation with their troops or their fleet, including observation and reconnaissance, regulation of artillery fire and liaison work; and second, pursuit or the attack of aircraft by aircraft; bombardment, day and night, of ground objectives; and attack by machine-guns and small cannon of troops and material on the ground. The first class of use increases and decreases with the size of the Army and the Navy. The second is dependent only upon the ability of a nation to produce and maintain aircraft. The reliance of the service upon aircraft has become such that it will be necessary to maintain a considerable air force as a part of every peace-time establishment. It will be impossible to train troops and prepare them adequately for war without it. Every country must be willing to assume the expense involved in producing aircraft for the peace-time training of its Army and Navy, no matter what the expense may be; so, we can expect in any future war to find at the beginning of hostilities the aircraft needed for immediate service with the Army and Navy.

It will be impossible for any country, no matter how wealthy, to maintain an industry capable of turning out aircraft at the rate required unless commercial aeronautics is successful. In any case, when war is declared, there will be a determined effort on the part of the belligerents to produce aircraft for war purposes just as fast as possible, and the size and training of the then existing industry, which will form a nucleus for expansion, will probably determine which belligerent will be able to gain control of the air. Furthermore, it is almost inconceivable that control of the air will not be one of the deciding factors in any future war.

Future Tactical Use of Aircraft

In any war with a first-class power, the tactical use of aircraft against enemy elements coming across the sea, whether in the air or on the water, will probably proceed along the following or similar lines:

(1) Long-range reconnaissance by rigid airship from some shore base to locate hostile air forces or hostile fleets. This will lead to combat between airships

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(2) After contact has been established between air forces, a battle or series of battles will occur between pursuit aircraft to determine the control of the air

(3) Control of the air having been established, aircraft will attack enemy ships, both surface and submarine. This will be by

(*a*) Direct attack. Attack aviation will engage ships of all characters with cannon and machine-guns, to occupy the personnel of the ships and prevent them from using their means of defense against aircraft. Such attacks will be carried out at low altitude and control will be by radio from the air, in addition to pre-arranged orders and ordinary signals

(*b*) Bombardment. When the attack aviation has engaged the hostile naval vessels, bombardment aviation will attack with projectiles of weights up to and probably exceeding one ton and designed to make direct hits on the vessels. Projectiles being considered for this purpose are thermite or burning types; those throwing smoke screens on the ship itself, to prevent the personnel from seeing objects around it; armor-piercing projectiles of various kinds, designed to penetrate protective decks; depth bombs, etc.

(*c*) Water torpedo attack. By bombardment airplanes carrying water torpedoes. This attack will be made under cover of the two attacks just described

(*d*) Submarine attack. Directed by radio from airplanes

Attack at night will be carried out in a manner similar to that of the day attack, with the additional use of flaming projectiles and parachute flares to blind the personnel and put out their searchlights.

It is significant that at the price of about $35,000 per plane, a fleet of a thousand bombardment planes could be acquired for the present price of one battleship.

Separate Air Service

As to my attitude with regard to the so-called separate air service, I have been contending all along for three things. First, the Army and the Navy should each retain its own air service; that is, the personnel and materiel necessary to carry on the work of the Army as a thoroughly balanced force, complete in all its parts, should be

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retained as a part of the Army. I consider that the taking away from the Army of the air-service personnel which is to function with the Army would be a very grave mistake. Too little cohesion existed between the ground troops and the air service during the war. I attribute this more to lack of intimate association than to anything else. The only way in which we can get mutual sympathy and cooperation is by having these arms of the service closer together. Second, the Army and the Navy each have special requirements in aircraft that would not be appreciated by any purely civilian agency, and each must carry on its own experimental development to the end that the special requirements can be met. After having once determined upon a type suitable for a special need, the matter of production should be turned over to some other agency. Third, all matters of production should be in the hands of some central agency. It seems logical that this should be a civilian agency, either independent of or subordinate to any of the present executive departments of the Government. This agency, in addition to handling production, should take care of all the so-called civil activities of the Government. These include the forest patrol, the coast and geodetic survey, rules and regulations for the navigation of the air, the licensing of pilots, inspection of aircraft and all things that must be covered before we can have thorough Government control of civil and commercial aeronautics.

REMARKS BY COL THURMAN H BANE

We have had in this country for a number of years an Army and a Navy working by themselves, trying to solve the problem of the defense of the country. We now have a youngster, an air service, that thinks perhaps it ought to be allowed to take a share in the solving of the defense problems of the country. It appears that it is high time that these two full-grown individuals and this youngster should be required to work as one unit for the defense of the country.

It might be desirable to have a single department of defense, a secretary of war, for example, or a secretary of national defense. Under this secretary of national defense an Army, a Navy and an Air Service might be combined, having a single general staff composed of officers of the Army, the Navy and the Air Service. The handling of all problems of defense would then be combined in one unit and coordination and liaison would

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exist, that certainly do not and cannot exist under the separate organizations we now have.

REMARKS BY AIR COMMODORE L E O CHARLTON

When I landed in this country about a year ago to take up my present appointment, I found the Aeronautical Show of 1919 in full swing. It can only be gratifying to realize, as all must do, how successful has been the endeavor of those in the industry to turn the science of aeronautics from the side-track to which it was shunted during the war toward the main line of commerce, because the commercial machine will undoubtedly mean more for the defence of the country in an emergency, if properly developed, than other forms. Although the progress of the last year has been steady, it cannot be said to have been very great in volume. The volume of production in the coming year might be increased, apart from the unlimited loosening of purse strings, by a country-wide propaganda education of the public. Propaganda in this form no longer exists in my own country; it was supplied to us by our enemies. No less than 50 per cent of the inhabitants of the British Isles, either directly or indirectly, were witnesses of or sufferers from the visitations of hostile aircraft during the war. They were thus provided with a free education as to their deadly effectiveness and taught the absolute need of an adequate air fleet. Thus was provided the incentive to the great public, with the result that now the total aeronautical energy of the country is amalgamated into a separate Government department and most of the funds at its disposal are devoted to experiment and research. You were deprived of that, but the penalty you pay is perhaps an optimistic outlook in the country at large as to the needs of aeronautics.

I will touch only in a general sense on the controversial matter which I am aware exists in this country as regards the need of a separate air service. No one knows better than I the different problems that different countries have; and that different countries have different and efficacious methods of solving the same problem. I will therefore conclude with the allegory that a growing tree can stand by itself; that the sapling even, if of sturdy growth, can grow straight; but that the tendril, unless it is deformed, must be supported.

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ADDRESS OF COMMANDER G C WESTERVELT

The future of naval aeronautics is bound up in the future of aeronautical science in general. Along with military and commercial aeronautics, naval aeronautics must be pushed ahead as far as possible. Before commenting upon the expectations of the naval service with regard to aeronautics, it will be interesting to review several features of its development thus far.

The first twelve-cylinder Liberty engine to fly, flew in a Navy flying-boat. It was first shown at the Bureau of Standards in Washington. I was very much interested in it, because the Navy had decided to plunge absolutely on the Liberty engine. They had decided to install it on all of the flying-boats they were going to use for submarine patrolling purposes. At this time the Liberty engine was not an approved instrument; so we were watching it with the greatest interest.

The engine was made the basis of the Navy program. Its success was so great, although it had many defects which had afterwards to be worked out, that we decided no mistake had been made. The risk we had taken in plunging on one engine and basing our entire program absolutely on its successful outcome, had been warranted by the remarkable skill of the engineers who had designed it. The result was that when the Liberty engines began to come through in improved condition, we were able to ship flying-boats abroad for use at the fifteen stations we had in European waters, in such numbers that more than two months before the signing of the armistice we stopped shipping them. This was made possible by the fact that the Liberty engine was remarkably successful and because most of the pioneer aircraft manufacturers in the United States were assigned to Navy production exclusively. It demonstrated conclusively that the pioneers in the airplane business were the ones who knew most about the plane business, they being able to get more quickly into the comparatively small-scale production that the Navy needed.

Navy Plans for Aircraft

Our plans for the future are mainly plans of development. Naturally, we do not expect, during the next year or two, any considerable quantity of production. We do

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not need it. But what we must undertake is development work along strictly naval lines. It has very little bearing upon types required for land work; the Navy has problems to meet which are peculiar to its service.

We cannot pretend to this Society and to the aircraft manufacturers that we will be able to assist in production matters to any great extent. We do not expect to have the necessary money during the next two or three years to encourage production. This is regrettable because we realize that we must look to the commercial development for a large part of our own naval development. We cannot use commercial machines, but we can use the same materials, manufacturing facilities, mechanics, designing skill and skill of every sort that enter the development and manufacture of commercial machines.

Separate Air Service

Regarding the question of the separate air service, I will comment briefly upon the attitude of the naval service. Very few Navy men have been called into the discussion. I feel absolutely certain that the Navy feels that to take naval aeronautics away from the naval service would be a very great mistake. The Navy thinks not in terms of the battleship service, the destroyer, the submarine or the air service, but purely in terms of the naval service. It cannot be realized by anyone except persons who have lived for some time in the atmosphere of the naval service, that the Navy is made up of various elements, all necessary to its whole, and that if any one of those elements is removed the whole is incomplete. In the naval service, we believe that if naval aeronautics were taken away and placed under a separate organization, it could not develop with the spirit of the naval service, or along the lines which the naval service considers necessary. Therefore, we feel, and fear, that naval aeronautics will come to a standstill if taken out of the naval service and placed under a separate organization.

So far as the personnel of the naval air service is concerned, we believe that its place is in the Navy as a part of the Navy. We want to stay in the Navy, we look with disfavor, even with fear, upon being transferred to a separate organization. This is not a selfish viewpoint, because the probability is that all members of the naval air service would, if transferred to a separate organization, benefit very much in rank and in emoluments.

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I wish to say that anyone who works for a separate air service, at the expense of the naval air service, is taking steps, so far as the Navy is concerned, which the people in the Navy believe will not be for the benefit either of the Navy or the country. They believe that those who are working with the object of maintaining in the Navy, and in the Army, the control of their own military aeronautical affairs, are working not only in the interests of the military arms, but of the country as a whole. We in the service look to you confidently to base your decisions only upon the cold logic of reasoning, and then cooperate with us if you can. We assure you that we will cooperate with you, and we look to you for assistance.

ADDRESS OF GEORGE H HOUSTON

When I was asked to talk here this evening, I was very directly reminded that this was to be an engineering meeting, and that there were certain things I was not to talk about. I have listened with a great deal of interest to the talks we have just heard and I want to say to the representatives of the Army and the Navy here that the point of view they have expressed is one that should receive the most careful and painstaking attention on the part of the Congress in this country, in working out this aircraft problem. I would also say, however, that there are certain political, psychological, financial and administrative aspects of the problem, which in the analysis they have made this evening have not been taken into consideration. I do not propose to discuss them this evening. I believe that there are two sides to this vitally important question, and I am frank to say that the final answer has probably not yet been reached. I hope it will be reached in a short time, because I believe the difference of opinion and the resulting deadlock are doing more to stagnate the development of aeronautics in this country than all other influences together.

I have been closely associated with the development of the aeronautical industry since it was practically nothing but a production industry for our Allies. I have given the future development of it considerable thought. The aspect of future development that has struck me more forcefully than any other is that before aeronautics can become of great importance to this country, it must be more generally understood by the people of this coun-

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try, as a whole; that is, they must grasp the problems that aeronautics will solve, and the problems that aeronautics brings. In other words, they must get the point of view of this new thing that has come into our lives, before real progress can be made.

The history of civilization, from its earliest inception, has been a story of the development of methods of communication and transportation. Man early learned to use animals as beasts of burden, and to transport himself by physical labor upon the surface of the water. He later learned to use the wind as a means of propulsion upon the water; but beyond this point little progress was made for many ages. With the invention of the steam engine, great strides were made in the development of the locomotive and the steamship. It is needless to call attention to the way in which these two developments have revolutionized man's entire point of view toward life. It is hard to believe that the first steamship crossed the Atlantic only one hundred years ago, that the first railroad crossed this continent scarcely fifty years ago, or that the first automobile was made in this country in 1893.

Great as has been the effect upon the life of man of the development of these modes of mechanical transportation, the ultimate effect of aerial flight will be still greater. Man dreamed of flying for hundreds of years. We read of how Leonardo da Vinci, among all of his enterprises in art and engineering, dreamed and worked for a solution of the great problem of human flight, but without success. This effort continued from generation to generation with apparently no progress toward the solution of the reason why man cannot fly as readily as the birds. Many of the greatest scientists of modern times have given much time and thought to the determination of this problem; but it remained for two unknown youths, with little technical education, to discover the principle upon which human flight depends.

Man successfully flew for the first time when the Wright brothers proved their invention by flying at Kitty Hawk, N. C., Dec. 17, 1903. It was not until 1908, however, that the world became convinced that human flight was possible. Many will remember how the papers scoffed at Wilbur Wright at LeMans, France, for his presumption in thinking he could fly, and how the sentiment reversed itself when his triumphant flights were witnessed. During the same year the

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Wright brothers flew before the rulers of England, France, Italy and Germany, and Orville Wright flew at Fort Myer near Washington. The result of these efforts was the recognition throughout the world of their contribution to the science of aerodynamics and to the art of flying. Others in America, France, England and Germany, were also studying this problem of human flight, but the progress was slow. Many of the best and most aggressive persons working for its solution were killed by accidents, and their work destroyed. During this period much speculation was indulged in as to the usefulness of the airplane and the dirigible for the practical requirements of man, but when in 1914 the world war began it was shortly discovered that aircraft are of great value in military operations. The science of aerodynamics and the practical production and use of aircraft were still in an embryonic condition. Probably no art or science in the world's history has developed so rapidly as the art of human flight since 1914. The history of this development when written will make the development of the railroad and the steamship appear very slow by comparison. In 1908 the Wright brothers sometimes flew as long as 30 min. at a time. In 1919, only eleven years later, and after five years of exclusive use of aeronautical equipment for purposes of warfare, we find the airplane and the dirigible coming into daily use in every part of the world for many kinds of military and commercial uses.

Looking over the entire field of aeronautical activity, we see before us the beginning of a vast industry whose growth throughout the world during the next decade will be phenomenal, and probably beyond the expectation of the most sanguine. This growth involves the solution of many serious problems, however, and I regret to say that they are not being given the consideration here in the United States that they deserve or that they are receiving abroad. It was the inventive genius of American citizens that first made human flight possible. Daring and resourceful American citizens first spanned the Atlantic by human flight, the initiative of an American Government official first made aerial mail transportation a practical success; but in general we are not giving to the solution of our aeronautical problems the farsighted constructive thought that it deserves and requires if we are to keep abreast of foreign progress. The problems involved in this development are complex and difficult

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and their practical solution can be achieved only by the thoughtful attention of everyone concerned. I group these problems into four general classes

(1) International relations
(2) National control
(3) Commercial, industrial and technical development
(4) Provision for national defense

International Relations and National Control

Due to the high speed of transportation and the great distances covered, human flight is of necessity an international activity. This is, of course, truer of European countries than it is of America; but even in America we are already confronted with the problem of planes flying across the border to and from Canada, Mexico, Cuba and the Bahamas.

Aeronautical transportation between the Bahama Islands, Cuba and Florida, promises to grow with unprecedented rapidity due to recent developments within the United States itself; so that even this country must recognize the international character of aviation and make provision accordingly. This aspect of the situation has long been given careful study by European countries and, as a part of the peace negotiations, a conference was held in Paris, attended by representatives of all the Allies, for the preparation of an international agreement setting forth the principles which shall govern the control of air flight between the nations of the world. This agreement was accepted by the representatives of the United States subject to the ratification of the Senate, with certain reservation which in the opinion of the American industry were justifiable and reasonable. This international convention was remarkable and a very effective start toward international aviation law; it has been ratified by every one of the Allies except the United States, Japan and Canada. Its early ratification by the United States would probably be followed shortly by its ratification by Canada, and would mean the establishment of effective international regulation of air flight on this side of the Atlantic.

This international agreement, however, involves certain undertakings on the part of the United States which deserve immediate and careful attention, whether the convention is ultimately ratified or not. These obligations

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pertain to the control of the construction and use of aircraft in general

(1) To prevent improper and dangerous craft being built
(2) To prevent craft being improperly operated, either through ignorance or carelessness
(3) To define the rules of aeronautical commerce in conformity with international practice; so that uniform methods of operation, signaling, landing, etc., will develop throughout the world

Industrial and Technical Development

Aeronautical transportation as a commercial activity cannot become a fact until conditions surrounding the use of aircraft are established in such a way as to create stability and safety of operation, regular routes of commerce and reasonable economy. Given reasonably intelligent construction of aircraft and correspondingly intelligent operation, there is little risk in aerial transportation, except as to the dangers involved in landing. These dangers can be almost entirely overcome by properly constructed and well-located landing fields.

The development and perfection of this equipment are the particular problems the members of this Society are being asked to cope with. I refer to this not in criticism of what has been accomplished in the past, which has been truly remarkable, but to emphasize the vital importance to the success of commercial aeronautical transportation, of continued development in this direction. This field is so great, involving as it does motive power, heavier-than-air and lighter-than-air craft, accessories and instruments of all kinds, that we must realize the wonderful possibilities that remain.

Progress is possible only through extensive laboratory and experimental work of an unusually expensive nature, as for instance the altitude flights that have recently been made by Major Schroeder and others in an effort to come to a clear understanding of the conditions of the upper atmosphere. It is not practical to expect the private enterprises now behind this infant industry to support all of this experimentation, particularly as the greater part of it is of immeasurable value to the Government for purposes of national defense and otherwise. While it is exceedingly undesirable for the Government to undertake to design its own craft, instead of developing such de-

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tailed design by private initiative through competition, yet it is desirable for the Government to carry on this fundamental experimental work. To this end there must be maintained an organization properly equipped for the testing out of any new equipment that is brought to it, and for the carrying on of such experimental work as is necessary to properly establish the science of aerodynamics.

There are no insurmountable difficulties in working out any of these problems, or in establishing these aspects of commercial aviation. The one great remaining difficulty, however, is almost insurmountable at present. I refer to the matter of reasonable economy of operation. It is at this point that the aeronautical industry requires the assistance of Federal, State and municipal Governments. Just as the nation and the communities have built a net-work of roads throughout the country for the transportation of vehicles, just as Federal and State Governments, and municipalities gave all possible encouragement in the early days through grants of land and otherwise to the construction of railroads, and just as the Federal Government and municipalities undertake today to develop our harbors and water-ways, so it is necessary the aeronautical transportation industry be helped to establish the conditions under which air flight must be carried on. I do not mean by this that the industry of aircraft production should be subsidized. The development of the production industry is in reality not the solution of this problem, in that it bears about the same relation to aeronautical transportation that the production of locomotives and freight cars bears to the railroad transportation problem. Given a profitable and well-organized aeronautical transportation industry, the production of aircraft and aircraft equipment will take care of itself upon a satisfactory and self-supporting basis; but in my opinion aeronautical transportation in the United States will develop with exceeding slowness and will be far outstripped by similar development in foreign countries unless the Government of the United States and the Governments of the States and municipalities, each actively participate in the development of flying routes, in the preparation and equipment of flying fields, in the provision of adequate signaling and communication systems, meteorological service and the carrying out of extensive technical experimentation. I am confident on the other hand that with well-established

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flying routes equipped with adequate flying fields properly located and provided with the resources above enumerated, commercial aviation will become a fact throughout all of this country to an extent undreamed of at the present time.

Providing for National Defense

The only practical way in which the Nation can be prepared with an adequate supply of aircraft for its protection in case of necessity is to develop a large aerial merchant marine, made up of an extensive personnel trained to constant flying, and a mass of flying and production equipment the greater part of which would be applicable to military purposes in case of need. I will grant at once that aircraft used for commercial purposes is not altogether effective, or even desirable, for military purposes. It would be effective, however, for internal transportation and training purposes, and the production facilities and organization used for making commercial craft and the technical facilities used in the designing and development of commercial craft would be immediately available for the production of military craft in the shortest possible time. It was the lack of this technical experience and of the production facilities and personnel that made the production of aircraft in the United States during the late war such an insurmountable problem. It would of course be necessary to have a nucleus of military craft and personnel trained to the highest possible degree in the science of aerial warfare. Such a military air service in time of war would maintain the same relation to the air service as a whole as the regular Army maintained to the Army of the United States during the late war.

Current Flight Mileage and the Future

Scarcely sixteen years ago the Wright brothers made four flights, the longest being 852 ft. During the eight months from May to December, 1919, in England alone in civil aviation, exclusive of the competition flights from England to Australia, over 590,000 miles were flown. When American, French, Italian, German, Japanese and other civilian aviation is included, and military aviation is considered, it will be seen that the human race flew in the past year probably in excess of 2,000,000 miles.

Today man has surpassed the flight of birds in every particular except one, the safety with which he alights. He has flown higher and farther and more rapidly than

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any bird that has ever lived or ever will live. It is only a matter of time when he will learn how to alight with security equal to that of his other attainments. If such progress has been made in the past sixteen years, let us consider what we may expect in the next ten and lay our plans accordingly.

The Society of Automotive Engineers has an opportunity during the next few years to be of great value in the development of this new industry, through the perfection of the mechanical equipment which it requires and through the exercise of its influence in bringing about the conditions necessary for the successful carrying on of commercial aeronautics.

THE HEAT-TREATING OF BRAZED FITTINGS FOR AIRCRAFT

By Archibald Black[1]

A tendency exists in most shops to assume that brazed joints cannot be successfully heat-treated. As a consequence, many fittings used in aircraft work and assembled by brazing smaller parts together are finished and installed without being heat-treated after the brazing operation. This practice causes parts to be used that not only do not develop the available strength of the material, but which are in some cases under internal stress due to the heating in the brazing operation. Recent experiments made at the Naval Aircraft Factory show that the assumption mentioned is entirely erroneous. The author considers this matter with a view to specifying the use of steels and brazing spelters which will permit the subsequent or perhaps the simultaneous heat-treatment of the parts.

The spelters required, their melting and approximate softening points to avoid the destruction of the brazed joint during heat-treatment, are discussed and data concerning them and the steels likely to be required for aircraft parts are presented in accompanying charts. Heat-treatment is then taken up and notes regarding the heat-treating of the tube struts used in aircraft work are given, the conclusion reached being that nothing is gained by the use of high-strength steel where the length divided by the least radius of gyration exceeds about 100.

[1]Engineer in charge of aeronautical specifications, Bureau of Construction and Repair, Navy Department, Washington.

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A tendency exists in most shops to assume that brazed joints cannot be successfully heat-treated. As a consequence, many fittings used in aircraft work and assembled by brazing smaller parts together are finished and installed without being heat-treated after the brazing operation. This practice causes parts to be used that not only do not develop the available strength of the material, but which are even, in some cases, under internal stress due to the heating in the brazing operation. It has been shown by some recent experiments, made at the Naval Aircraft Factory, that this assumption is entirely erroneous. It is therefore advantageous to consider this matter with a view toward specifying the use of steels and brazing spelters which will permit the subsequent or perhaps the simultaneous heat treatment of the parts.

Materials

Considering the spelters required for such work, it is necessary to know not only their melting but also their approximate softening points, to avoid the destruction of the brazed joint during heat-treatment. Fig. 1 gives the approximate melting points and tensile strengths of several different compositions which provide a wide range for selection. These values are, however, subject to slight modification, due to the presence of some 1 to 1.25 per cent of impurities in commercial spelters, yet

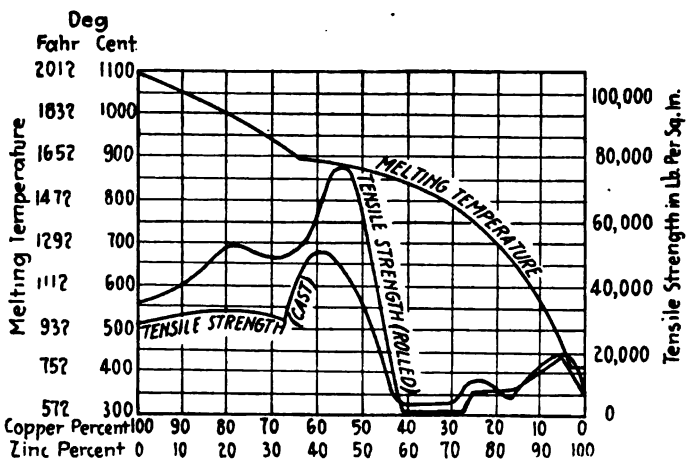

Fig. 1—Approximate Melting Points and Tensile Strengths of Various Spelters

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TYPICAL LIST OF STEELS USED IN AIRCRAFT WORK,

Steel	End of Upper Critical Range on Heating, deg. fahr.	Heat-Treatment		
		Hardness After Oil Quench		Drawing Temperature, deg. fahr.
		Brinell	Shore Scleroscope	
Mild carbon (0.15 to 0.35 per cent carbon),	See Fig. 3	150 to 225	30 to 40	800 to 1,300
Medium carbon (0.35 to 0.55 per cent carbon),	See Fig. 3	225 to 325	40 to 55	700 to 1,200
High carbon (0.55 to 0.75 per cent carbon),	See Fig. 3	325 to 380	55 to 70	250 to 1,000
High carbon (0.75 to 1.05 per cent carbon),	See Fig. 3	380 to 420	70 to 90	250 to 1,000
Nickel (0.20 per cent carbon, 0.50 to 0.80 per cent manganese, 3.25 to 3.75 per cent nickel),	1,390 to 1,330	350 to 550	50 to 80	900 to 1100
Nickel (0.40 per cent carbon, 0.50 to 0.80 per cent manganese, 3.25 to 3.75 per cent nickel),				600 to 900
Low nickel chromium (0.35 to 0.45 per cent carbon, 0.50 to 0.80 per cent manganese, 1.00 to 1.50 per cent nickel, 0.45 to 0.75 per cent chromium),	1,385	400 to 600	60to100	700 to 1,100
Chromium-vanadium (0.35 to 0.45 per cent carbon, 0.50 to 0.80 per cent manganese, 0.80 to 1.10 per cent chromium, over 0.15 per cent vanadium).	1,425	400 to 600	60to100	800 to 1,400

for the purpose of this work they may be considered correct, and it is recommended that the curve of tensile strength of cast material be assumed correct for the strength of the spelter in a brazed joint.

More detailed information of the properties of spelters is given by Hofman[2]. Information about softening points is not so definite. Something can be learned from the equilibrium diagram for brasses given by Hofman,[2] and also from a test made by the Naval Aircraft Factory which showed that a brazing wire of 80-20 brass mixture

[2]Metallurgy of Copper, Hofman.

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WITH THEIR APPROXIMATE PROPERTIES

AFTER HEAT-TREATMENT

Hardness		Tensile Test		
Brinell	Shore Scleroscope	Ultimate Strength, lb. per sq. in.	Yield Point, lb. per sq. in.	Elongation in 2 in., per cent
180 to 130	30 to 20	90,000 to 60,000	60,000 to 40,000	18 to 26
250 to 180	40 to 30	110,000 to 90,000	80,000 to 60,000	16 to 20
325 to 250	65 to 40	160,000 to 125,000	125,000 to 90,000	2 to 10
400 to 325	90 to 65	250,000 to 160,000	200,000 to 125,000	2 to 10
275 to 200	44 to 34	140,000 to 108,000	110,000 to 78,000	20 to 25
400 to 295	60 to 44	215,000 to 155,000	190,000 to 130,000	12 to 16
360 to 245	60 to 42	204,000 to 112,000	168,000 to 94,000	10 to 17
440 to 210	60 to 25	220,000 to 105,000	190,000 to 65,000	10 to 20

appreciably softened at about 50 deg. fahr. below its melting point.

Considering the steels likely to be required for the construction of aircraft parts, by consulting specifications issued by the Air Service and by the Bureau of Construction and Repair of the Navy Department, it is found that a typical list such as that given in the accompanying table can be compiled. This table is reproduced from aeronautical specification No. 89a of the Bureau of Construction and Repair, Navy Department, for the heat-

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treatment of brazed joints and is based upon work done by the division of metallurgy of the Bureau of Standards.

As is well known, when steels are heated or cooled, irregularities in the rise or fall of temperature take place at certain periods, indicating internal changes in the material. These so-called critical points are actually short ranges but are known in steel technology as the Ac_1, Ac_2 and Ac_3 points where they occur during heating and the Ar_3, Ar_2 and Ar_1 points where they occur during cooling. Fig. 2 is a typical heating and cooling curve, showing the transformations for a steel of 0.3 per cent carbon and 0.7 per cent manganese, and Fig. 3 is the "equilibrium diagram"[3] for straight carbon steels and is correct for 0.05 to 0.80 per cent carbon, at temperatures of 700 to 950 deg. cent., the critical points being clearly shown. Such diagrams are usually only approximate, however, as they are affected by the impurities always found in commercial steels. An extended discussion of the heat-treatment and metallography of steel will be

[3]Notes on the Critical Ranges of Some Commercial Nickel Steels, Scott, *Mining and Metallurgy*, February, 1920.

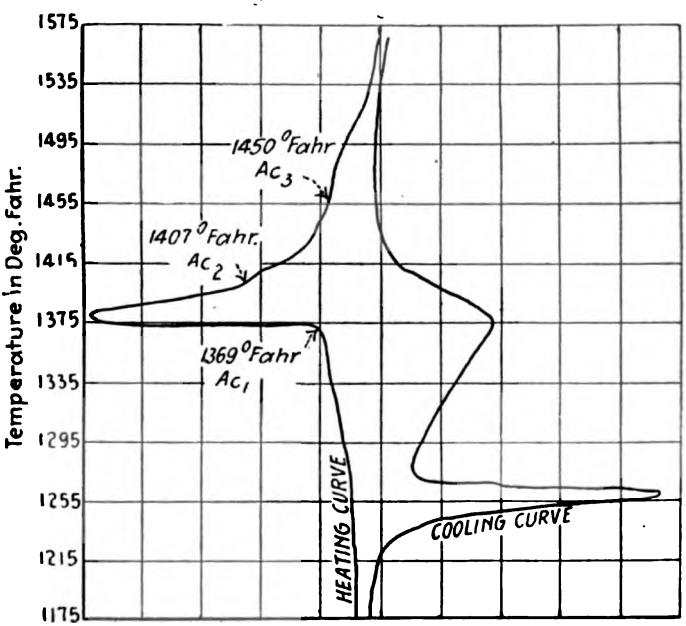

FIG. 2—TYPICAL HEATING AND COOLING CURVE

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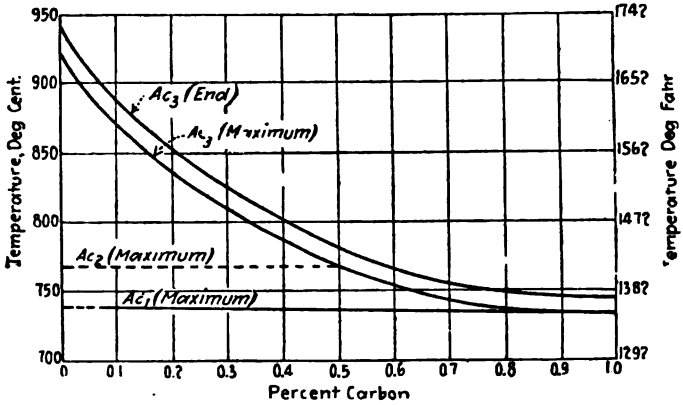

FIG. 3—EQUILIBRIUM DIAGRAM FOR STRAIGHT CARBON STEELS

found in Sauveur,[4] Bullens[5] and other standard works on this subject.

In the heat-treatment of a steel it is necessary to quench it from a temperature slightly above the upper end of its higher critical range, the actual temperature depending largely upon the size of the part being treated. As a general rule this temperature should be at least 50 deg. fahr. above, and if information is not at hand concerning quenching temperature, it is advisable to consult the steel manufacturer for advice on the entire heat-treatment, rather than to attempt any experiments. The Midvale Steel & Ordnance Corporation issued a booklet containing much information about its series of alloy and tool steels, which is of general value. If the parts are to be brazed and heat-treated, a spelter should be selected such that the quenching temperature of the steel employed will be at least 125 deg. fahr., that at which the brazing spelter melts, and, if possible, this difference should be greater to avoid danger of destroying the brazed joint during heat-treatment.

HEAT-TREATMENT

If the parts are to be brazed first and heat-treated in a separate and subsequent operation, the two operations can be handled in the usual manner, except that it may be found necessary to take special precautions to avoid warping during heat-treatment. It would seem advisable, however, to rivet, spot-weld or otherwise fasten the parts together before brazing, so as to prevent trouble

[4]Metallography and Heat-treatment of Iron and Steel, Sauveur.
[5]Steel and Its Heat-treatment, Bullens.

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from slippage of the joints during the subsequent heating. This practice of fastening parts together before brazing is in use in many shops at present and has been found to facilitate rather than to hold up production in most cases. Boulton[6] gives a detailed discussion of brazing.

The operations of dip brazing and heat-treating can be combined by selecting steels and brazing spelters which have the necessary quenching and melting temperatures respectively. In this method the brazing spelter should be maintained sufficiently above the specified quenching temperature of the steel to insure quenching at the proper point. If possible, a brazing spelter should be selected which has a melting point sufficiently above the specified quenching temperature of the steel to permit the practice of allowing the brazing to set slightly before quenching. If, however, the temperature of the brazing pot is allowed to approach 1750 deg. fahr., the composition of the spelter will be subject to a gradual change, due to the rapid volatilization of the zinc, with a resultant rise in its melting point. The parts should be allowed to remain in the pot sufficiently long to raise the temperature of all of the material to that of the spelter and should then be withdrawn and immediately quenched in accordance with the instructions of the heat-treatment being used. The reheating and drawing operations can then be followed in the usual manner.

As the combinations of processes described are new to the workmen, it is very advisable to proceed with caution in attempting to introduce them into the shop. Once the workmen become familiar with the methods and the proper materials have been determined and obtained, they possess considerable advantage in permitting the designer to make use of the important gain in strength due to heat-treatment, with the consequent lightening of the larger parts.

Notes on Tubes

It is well to mention, however, that no material advantage will be gained by heat-treating many of the tube struts or frames used in aircraft work, inasmuch as these are loaded as columns when in service. An examination of Euler's formula for crippling loads of long columns will show that the strength of such columns is determined by the form of the column and the modulus

[6] Brazing, Welding and Soldering in Aeroplane Construction, Boulton, *Aerial Age*, Oct. 6, 1919.

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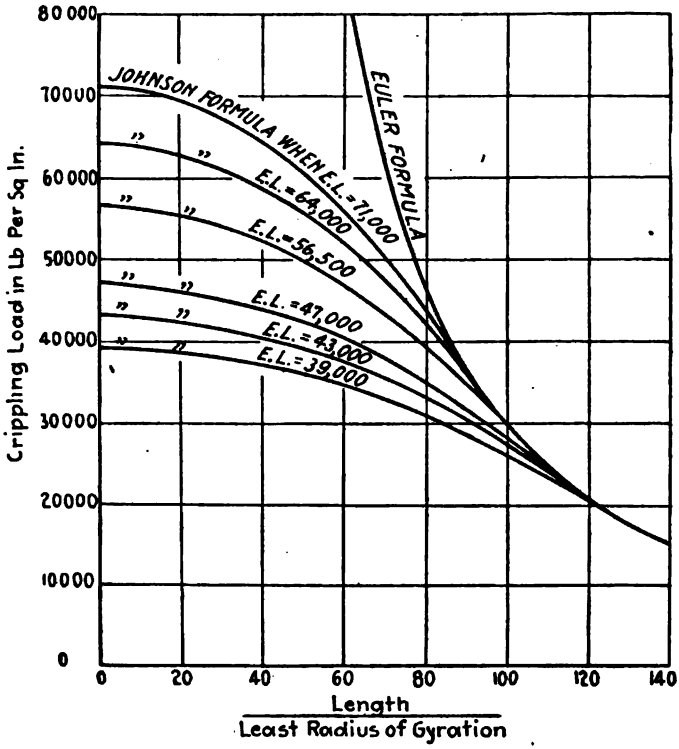

FIG. 4—COMPARISON OF EULER'S FORMULA WITH JOHNSON'S FORMULA FOR DIFFERENT ELASTIC LIMITS

of elasticity of the material used, the strength of the material not entering into the equation. Many tests have shown that the modulus of elasticity of steel is practically unaffected by heat-treatment, in addition to varying but little with great differences in the chemical composition. Thus, for example, a strut of heat-treated alloy-steel tubing will cripple at practically the same load as a strut of the same dimensions but of annealed low-carbon steel, providing (*a*) that the slenderness ratio is sufficiently high to justify the use of Euler's formula, and (*b*) that the ends are designed to transmit the loads without local failure. Fig. 4 shows the graph of Euler's formula, together with the graphs of Johnson's formula for various elastic limits, corresponding to different steels, and illustrates very plainly that nothing is gained by the use of high-strength steel where the length divided by the least radius of gyration exceeds about 100.

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MAINTAINING AIRPLANE ENGINE POWER AT GREAT ALTITUDES

By Lieut-Col V E Clark,[1] U S A

Following the 1917 recommendation of the Bolling Airplane Mission that great energy be devoted to the development of means to maintain a high proportion of the power of airplane engines at great altitudes, some very creditable work was done. A recent flight test at 20,000-ft. altitude indicates a resultant marked increase in airplane performance. Interest in this development should be extended. The purpose of the paper is to indicate the possibilities and limitations of increasing airplane speed by introducing means to maintain high engine power at great altitudes. The DeHaviland-Four is selected as being an airplane typical of present practice and the performances that might be obtained at different altitudes are approximately computed, with various assumed ratios of the actual engine power at the altitude to the total weight of the airplane in every case.

The accompanying series of curves give the various coefficient results. The method by which the values of the coefficients were obtained is stated and is of assistance in reading and applying the charts. All values are based upon results obtained from full-scale flight computations and not solely upon wind-tunnel tests.

The mathematical notation employed throughout is specified. The computations are followed through, showing how the algebraic values of the coefficients are determined, the gains from maintaining engine power at great altitudes being stated in a somewhat similar manner and directions given for entering the charts and obtaining the desired values. A comparison between actual and hypothetical airplanes is then made by mathematical analytic methods, and the suggestion advanced that engineers go through a few numerical examples, following the methods shown, using the accompanying charts and noting results.

In the summer of 1917, the Bolling Airplane Mission to Europe recommended in an official report that our engineers direct especial energy toward the development of means to maintain a high proportion of the power of airplane engines at great altitudes. Some very creditable work has since been done by at least two

[1]Engineering division, Air Service, Dayton, Ohio.

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engineers as a result of this suggestion, and a recent flight test at an altitude of 20,000 ft. indicates a resultant marked increase in airplane performance. It is felt, however, that interest in this development should extend to more of our engineers. The purpose of this paper is therefore to indicate the possibilities and limitations of increasing airplane speed by introducing means to maintain high engine power at great altitudes. I have attacked the problem by selecting the DeHaviland-Four as being an airplane typical of present practice, and by endeavoring to compute approximately the performances that might be obtained at different altitudes with various assumed ratios of the actual engine power at the altitude to the total weight of the airplane in every case.

The accompanying series of curves giving the values of the various coefficients results. Airplanes of greater aerodynamic efficiency, resulting for instance from the elimination of exposed wires, struts, wheels and the like, without sacrificing airfoil efficiency, would, of course, have greater speed for the same power-weight ratios. The method by which the values of the coefficients were obtained will be of assistance in reading and applying the charts. All values are based upon results obtained from full-scale flight computations and not solely upon wind-tunnel tests.

δ = relative density of air
P_h = actual horsepower developed by the engine at the altitude assumed
P_o = engine power at sea level
W = the total weight of the airplane in pounds, when leaving the ground
S = surface loading or the total weight of the airplane in pounds divided by the net square feet of area of the main planes, including flaps
e = the propeller efficiency under the conditions assumed. This usually varies from 0.70 to 0.80 throughout the range of working speeds of advance and of revolution
V = the velocity of the airplane through the air in statute miles per hour. Because of winds, V has no relation to the speed of the airplane with respect to the ground. Unless otherwise noted, V is the *maximum possible horizontal air speed*
A = the net area in square feet of the main planes, including flaps
T = the propeller thrust in pounds per square inch
C = in general, any coefficient whose value varies with the angle of incidence

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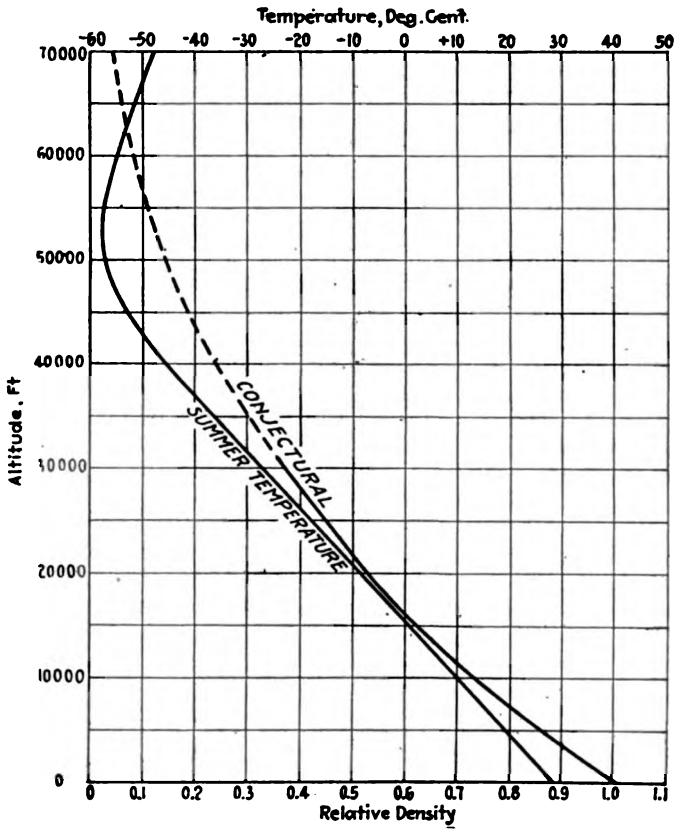

FIG. 1—CURVE OF RELATIVE DENSITY AND ALTITUDE

The notation employed throughout the paper is given on page 547.

Fig. 1 shows an approximate curve of relative density plotted against altitude. When consulting this curve, it must be borne in mind that the portion of the curve above 30,000 ft. is entirely conjectural and must only be considered as very approximate. A more exact method of computation would be to deal with values of density only, not considering altitude. Should means be developed for rising to great altitudes, further meteorological data as to densities, temperatures, wind velocities, etc., during various seasons and in various latitudes, will directly become necessary.

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$mg = W =$ total lifting force $= C_z \delta A V^2$, hence

$$\frac{W}{A} = S \text{ or, } S = C_z \delta V^2$$

$$V = C_1 \sqrt{\frac{S}{\delta}} \text{ or, } C_1 = \sqrt{\frac{\delta}{S}} \qquad (1)$$

Values for C_1, for any airplane geometrically similar to the DeHaviland-Four which is a tractor biplane with R. A. F. 15 airfoil section, an aspect ratio of ± 7 and a gap-chord ratio of ± 1 are given in the curve in Fig. 2.

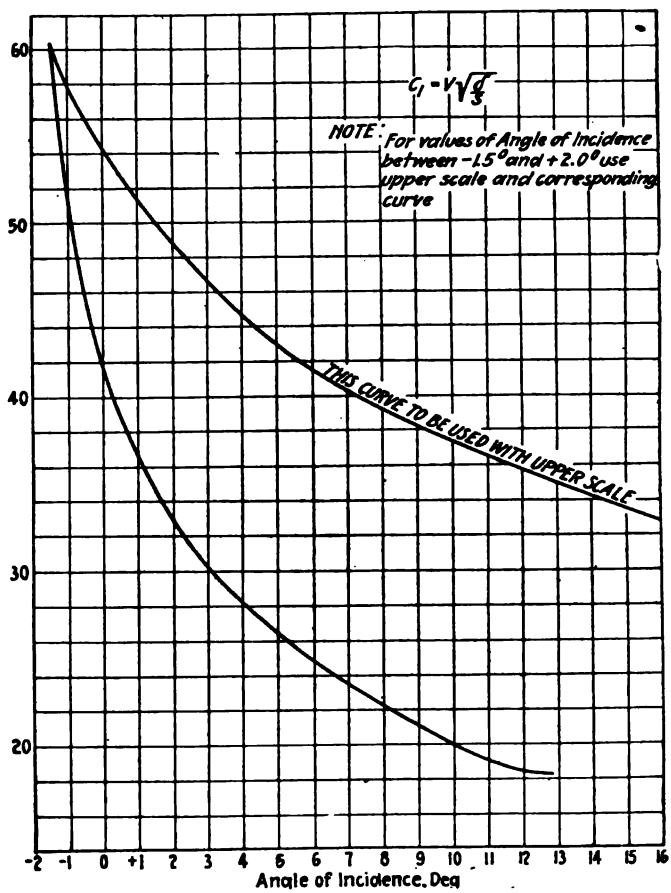
$C_1 = V\sqrt{\frac{\delta}{S}}$
NOTE: For values of Angle of Incidence between -1.5° and +2.0° use upper scale and corresponding curve
THIS CURVE TO BE USED WITH UPPER SCALE
60
50
40
30
20
-2 -1 0 +1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Angle of Incidence, Deg

FIG. 2—CURVE GIVING VALUES OF C_1 FOR AIRPLANES THAT ARE GEOMETRICALLY SIMILAR TO THE DEHAVILAND-FOUR

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These have been arbitrarily plotted against the values of the angle of attack of the main planes. The mean tangent chord is the reference base.

The total resistance of the air to airplane advance in horizontal flight, in pounds per square inch, equals the propeller thrust in pounds per square inch if there is no acceleration or, $C_2\delta AV^2$.

$$T = \text{resistance} = C_2\delta \frac{W}{S} V^2, \text{ hence} \qquad (2)$$

$$C_2 = \frac{ST}{\delta WV^2}$$

The engine horsepower required to generate the propeller thrust is

$$\frac{C_2\delta WV^3}{375\,Se}$$

$$P_h = \frac{C_2\delta WV^3}{Se}, \text{ hence} \qquad (3)$$

$$C_2 = \frac{P_h Se}{\delta WV^3}$$

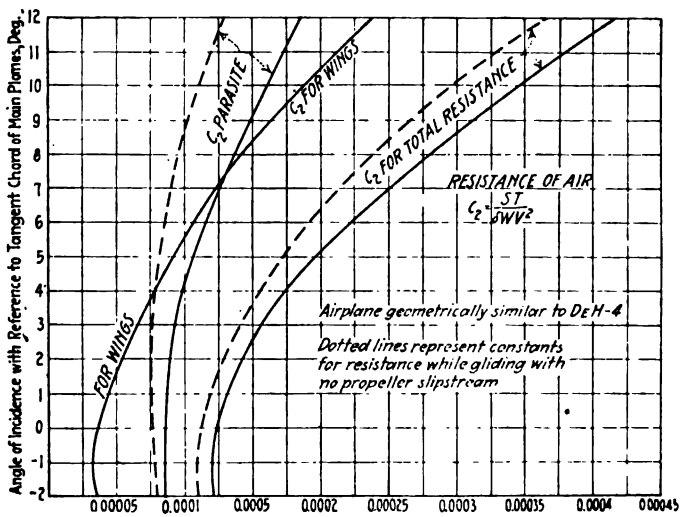

FIG. 3—CURVES GIVING VALUES OF C_2 FOR AIRPLANES THAT ARE GEOMETRICALLY SIMILAR TO THE DEHAVILAND-FOUR

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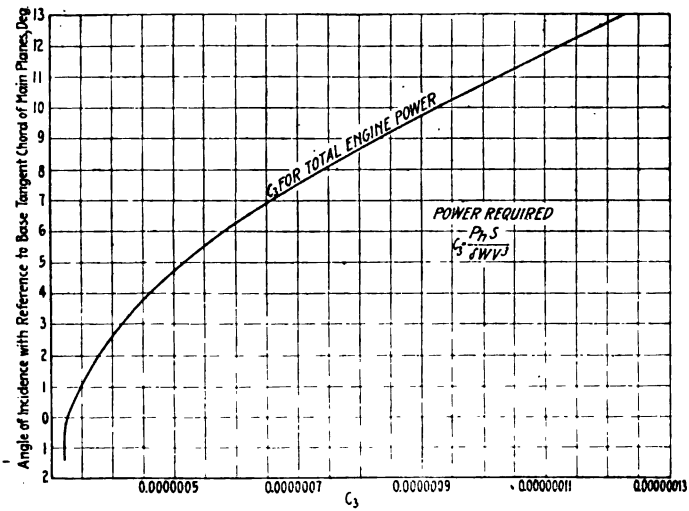

FIG. 4—CURVES GIVING VALUES OF C_3 FOR AIRPLANES THAT ARE GEOMETRICALLY SIMILAR TO THE DEHAVILAND-FOUR

Values for C_2 for machines geometrically similar to the DeHaviland-Four are shown in Fig. 3. The character of the curve of C_3, for parasite resistance with slipstream, changes, of course, with any variation in the propeller pitch or the air speed. Values for C_3, for the same type, are shown in Fig. 4. For airplanes in which the proportion of total area of cross-section of fuselages to area of main planes is greater than in the case of the DeHaviland-Four, the proportion of C_2 and C_3 for parasite resistance will be higher and vice versa.

Referring to Fig. 3, it is interesting to note that the theoretical limit of diving speed of the DeHaviland-Four is, with an angle of incidence of — 1.0 deg.

$$\sqrt{\frac{\cdot\ S}{0.000109\ \delta}}$$

Or, if the wing loading equals 9 lb. per sq. ft., the diving speed equals 287.2 m.p.h. at sea level. This is not exact. For a vertical dive, the angle of incidence is that giving zero lift and the drag coefficient is higher than the minimum. On the other hand, if the drag coefficient is the minimum, there is some lift, the drag is less than the weight and the dive is not quite vertical.

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The gliding angle, referred to horizon, with no power, is

$$tan^{-1}\left(\frac{C_2\delta V^2}{S}\right), \text{ hence}$$

$$V = C_1\sqrt{\frac{S}{\delta}} \qquad (4)$$

At an 8-deg. angle of incidence, at sea level, the wing loading equals 7.5 lb. per sq. ft., minus V (see Fig. 2), equals 60.9 m.p.h. The gliding angle (see Fig. 3) equals 1÷8.6 or 6 deg. 39 min.

From equation (3) we derive

$$\frac{W}{P_h} = \frac{Se}{C_3\delta V^3}, \text{ or } V = \sqrt[3]{\frac{P_h Se}{C_3 W\delta}}, \text{ but} \qquad (5)$$

as equation (4) gives a value for V, we obtain

$$\frac{W}{P_h} = \frac{e\sqrt{\delta}}{C_1^3 C_3\sqrt{S}} = \frac{e}{C_1^3 C_3}\sqrt{\frac{\delta}{S}} \qquad (6)$$

If we make $C_4 = C_3^2\, C_1^4$ we have

$$\delta = C_4 S\left(\frac{W}{P_h e}\right) \text{ or,} \qquad (7)$$

$$C_4 = \frac{\delta}{S}\left(\frac{P_h e}{W}\right)^2$$

Values for C_4 for airplanes geometrically similar to the DeHaviland-Four are shown on the curves in Fig. 5. The values of C_4 in these curves are not exact. For convenience in rapid, rough calculations, these have been corrected to care for the discrepancy in the value of W. When using Fig. 5 with equation (7), the value of W is the weight when leaving the ground and not the actual weight during flight tests. The consumption of fuel will, therefore, reduce W.

Gains from Maintaining Power at Great Altitudes

If an engine of the water-cooled type is used, with average modern-practice compression ratios and volumetric efficiency and having proper altitude carbureter control but no other device or means to maintain power

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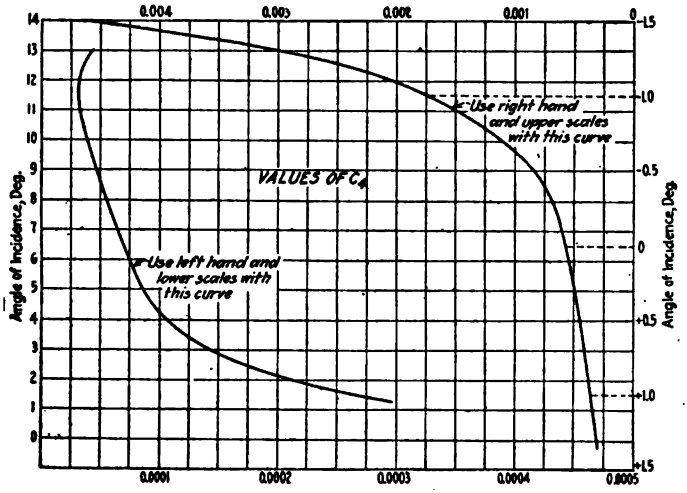

FIG. 5—CURVES GIVING VALUES OF C_L FOR AIRPLANES THAT ARE SIMILAR GEOMETRICALLY TO THE DEHAVILAND-FOUR

at great altitudes, we can assume, to obtain *rough* results, that

$$P_h = P_o(\delta)^{\frac{1}{0.75}} \tag{8}$$

No account has been taken in equation (8) of the variation with altitude of the percentage distribution of the various gases in the atmosphere. In fact, about 20.8 per cent of the volume of the air at sea level is oxygen in the middle latitudes. This increases to 21.1 per cent at 30,000 ft. and decreases to 18.6 per cent at 60,000 ft.

Substituting in equation (7) the value of P_h as obtained from equation (8), we obtain

$$\delta = C_L S \left(\frac{W}{P_o(\delta)^{\frac{1}{0.75}} e} \right)$$

Representing the fractional exponent of δ by the symbol Δ, we have

$$\delta^{(1+2\Delta)} = \frac{C_L S W^2}{P_o^2 e^2} \tag{9}$$

Working the other way

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$$C_4 = \frac{P_o^2 e^2 \delta^{(1+2\Delta)}}{SW^2}$$

Fig. 6 gives a curve of δ plotted against $\delta^{(1+2\Delta)}$, so that the value of either is directly obtainable from the other. It also gives a curve of δ^{Δ}, for use with equation (8).

From equations (7) or (9) and equation (4), the approximate high speed can be obtained at any altitude desired, having given the values for power, weight and surface area, the method being as follows:

First enter Fig. 1 and obtain the value of δ for the altitude desired. The only unknown quantity in equations (7) and (9) is then C_4. After obtaining the value of C_4, enter Fig. 5 and obtain the value for the angle of incidence. Then, from Fig. 2, for this angle of incidence, obtain the value of C_1. The high speed is then obtained by using equation (4).

With an airplane of a different geometrical and aerodynamical type from that of the DeHaviland-Four, having given P_h or P_o, S and *the horizontal high speed at any known altitude,* we can roughly predict its high speed at all altitudes, its ceiling, etc. The method is to substitute the known quantities V, S and δ, in equation (4), the value of δ being known from Fig. 1, and so obtain the value for C_1. Then, from Fig. 2, obtain the value of the angle of incidence. From Fig. 5 get the value of C_4 for this angle of incidence and substitute this in equation (7), obtaining a new hypothetical value for W, with which we then proceed, using C_1 and C_4 in equations (4), (7) and (9).

The stalling speed for any surface loading value and at any altitude can be obtained from the equation

$$V_s = C_{1s} \sqrt{\frac{S}{\delta}}$$

Values of C_{1s}, for various arrangements of planes with airfoils of sections R. A. F. No. 15, United States Army thick section No. 4 and United States Army No. 16, extreme cases, are shown in the table on page 557. It is assumed that the gap-chord ratio is between 0.95 and 1.10, and that in no case has any plane an opening in its center.

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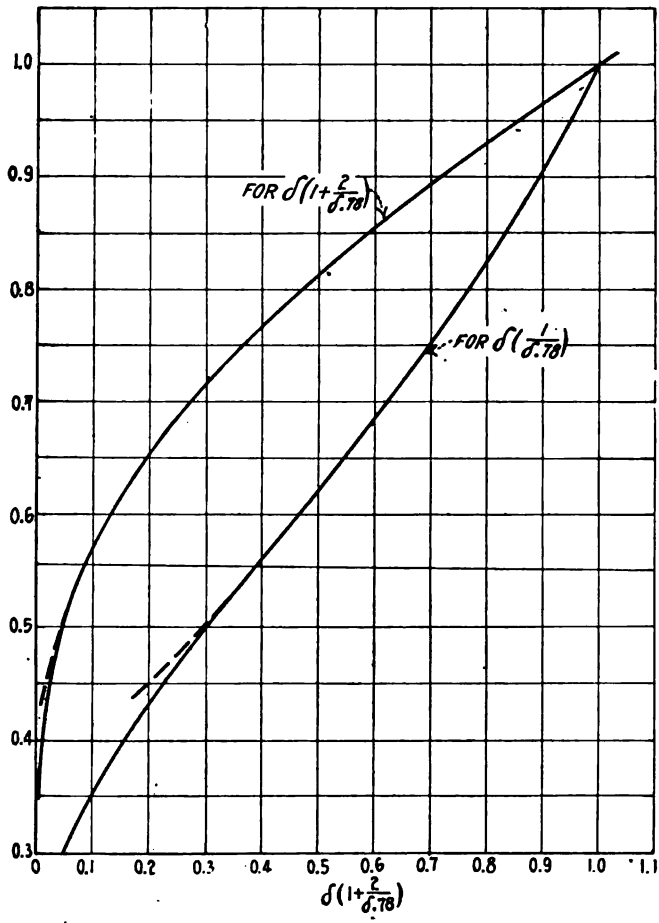

FIG. 6—CURVES GIVING VALUES OF THE FACTORS USED IN THE CALCULATIONS

COMPARISON OF ACTUAL AND HYPOTHETICAL AIRPLANES

Let us compare the speed of a present-day airplane with that of an hypothetical airplane in which is installed a means of maintaining its power constant at all working altitudes. Looking toward the future, it will be interesting to assume that the total airplane weight is the same in each case, 5000 lb. If the engine develops 500 hp. at sea level and the net area of the main planes is 556 sq. ft. in each case, then $S=9$.

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In each case let us arbitrarily assume that under full throttle, the altitude and speed for horizontal flight are such that the angle of incidence required for sustentation is 2 deg.

The development of the variable-pitch propeller which, most fortunately, is contemporary with that of the supercharger, is leading in the desired direction, however. The supercharger would, relatively, be of little value without the variable-pitch propeller which, set at a very low pitch, permits climbing away from the ground, and, set at a very high pitch, should show good efficiency at very high airplane speeds, in air of very low density.

Case I. The engine power decreases with an increase in the altitude at normal present-day rate, with no novel means of maintaining it.

The following values are taken, or are already given:

$S = 9$ Angle of incidence $= 2$ deg.
$W = 5000$ lb. C_4, from Fig. 5 $= 0.00021$
$P_o = 500$ hp.
$e = 80$ per cent

$$\delta^{(1+2\Delta)} = \frac{0.00021 \times 9 \times (5000)^2}{(500)^2 \times (0.80)^2} = 0.295$$

From Fig. 6 we obtain a value of 0.714 for $\delta^{(1+2\Delta)}$. From Fig. 1, the altitude corresponding to this is 10,900 ft. Substituting in equation (4) the value of C_1 for 2 deg. obtained from Fig. 2, which is 32.8, we obtain

$$V = 32.8\sqrt{\frac{9}{0.714}} = 116.5 \text{ m.p.h.}$$

Case II. Means are installed for maintaining the engine power constant with changes of altitude.

We will in this case assume a constant propeller efficiency of 0.80. From a practical standpoint, the maintenance of such an efficiency, constant at various speeds and in different densities, is today impossible.

We now assume that the total airplane weight in pounds divided by the horsepower developed by the engine at the altitude for a 2-deg. angle of incidence = 10. This is a very liberal assumption, and surely looks well into the future.

From equation (7)

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VALUES OF $C_1 s$ FOR VARIOUS ARRANGEMENTS OF PLANES AND DIFFERENT AIRFOIL SECTIONS

Number of Planes	Airfoil Section	Aspect Ratio	Value of $C_1 s$
Monoplane	R.A.F. 15	5	17.8
		7	17.3
	U.S.A.-T.S. 4	5	14.4
		7	14.0
	U.S.A. 16	5	18.8
		7	18.3
Biplane	R.A.F. 15	5	18.6
		7	18.3
		9	18.1
	U.S.A.-T.S. 4	5	15.3
		7	15.0
		9	14.8
	U.S.A. 16	5	19.6
		7	19.3
		9	19.0
Triplane	R.A.F. 15	7	18.5
		9	18.2
	U.S.A.-T.S. 4	7	15.3
		9	15.0
	U.S.A. 16	7	19.4
		9	19.1

$$\delta = C_d S\left(\frac{W}{P_{he}}\right)^3$$

$$= 0.00021 \times 9\left(\frac{5000}{500 \times 0.8}\right)^3 = 0.296$$

This is an altitude of 35,400 ft. Referring to Fig. 1 for a value of C_1, we have

$$V = 32.8\sqrt{\frac{9}{0.296}} = 181 \text{ m.p.h.}$$

Case III. Suppose we fly at the same altitude in Case II as in Case I. Then, from equation (7),

$$C_d = \left(\frac{P_{he}}{W}\right)^3$$

$$= \frac{0.714}{9}\left(\frac{500 \times 0.8}{5000}\right)^3 = 0.00508$$

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Reference to Fig. 5 will give a value of +0.22 deg. From Fig. 2, $C_1=40.2$, and

$$V = 40.2\sqrt{\frac{9}{0.714}} = 143 \text{ m.p.h.}$$

Following this method of computation and using equations (7) and (4) and Figs. 1, 2 and 5, we obtain the curves in Fig. 7, which presents a comparison between high speeds in the two previous cases at all altitudes.

Now let us obtain the approximate theoretical absolute ceiling of the machine of the second case, maintaining our assumption of constant power at all altitudes.

At absolute ceiling, the angle of incidence of this type of airplane is about 10 deg. This is the point of best lift-drag ratio. From Fig. 5, $C_L=0.0000385$, and from equation (7),

$$\delta = C_L S\left(\frac{W}{P_{he}}\right)^2 = 0.541$$

Assuming that the density-altitude curve in Fig. 1 is approximately correct, the altitude is 66,000 ft. and

$$V = 20 \times \sqrt{\frac{9}{0.541}} = 258 \text{ m.p.h.}$$

No suggestion will here be made as to the basic principle of the device or means for maintaining power with low density. Among the solutions suggested are a supercharging device at each cylinder to increase the compression and introduce more oxygen, a rotary air compressor driven by an exhaust gas turbine, or through gearing by a shaft, special fuels and the combination of the special fuel with a higher compression, etc. Designers must consider the extreme low temperatures encountered. Note the curve in Fig. 1.

Incidentally, the air compressor for the engine intake might also be used to maintain good pressure and introduce extra oxygen in a necessarily sealed compartment occupied by the personnel.

If engineers should go through a few numerical examples, following the method shown above, using the accompanying curves and noting results, they might become interested in development along this line.

In the general latitude of New York, Chicago and San Francisco, suppose that we could in certain seasons of

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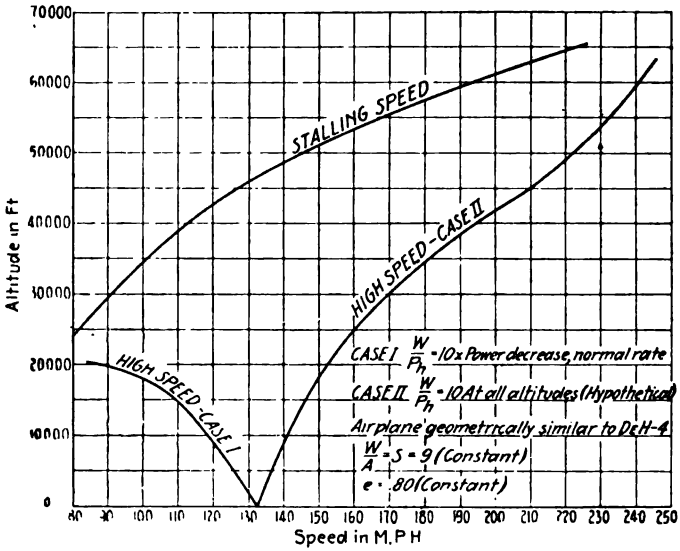

FIG. 7—COMPARISON OF SPEEDS OBTAINABLE FROM AN AIRPLANE ENGINE WITHOUT AND WITH MEANS FOR MAINTAINING CONSTANT POWER AT ALL ALTITUDES

the year, by rising to an altitude of about 40,000 ft., encounter a wind current having a velocity of 100 m.p.h., whose direction is such as to be "under the tail." If we could maintain a speed through the air of 200 m.p.h. at this altitude our speed over the ground would be 300 m.p.h. We could then, in flying time, go from Chicago to New York in 3 hr. and from San Francisco to New York in 9 hr.

Speed of travel or transportation makes for saving in time which, from the practical commercial standpoint, is tantamount to the elimination of space. Bringing San Francisco as near to New York as Pittsburgh now is by train, if it can be done, is a matter of tremendous importance. We should, therefore, look well into all means offering even the appearance of possible feasibility which may be suggested for helping toward this eventual accomplishment.

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LANDING RUN AND GET-AWAY FOR STANDARD AIRPLANES

By Alexander Klemin[1]

The length of the landing run constitutes one of the greatest practical airplane problems, particularly when using the fields now available. A fast, heavily-loaded machine has excellencies of its own but is not likely to be capable of a short run; a powerfully-acting tail-skid, while giving full braking effect, is likely to damage a field and at the same time impose undue stresses upon the fuselage. In the case of forced landings, it is particularly important to have as short a landing run as possible. The mechanics of the airplane in the air have been exhaustively studied, but no mathematical considerations or conclusions are available concerning landing runs.

In a three-point landing, with the engine shut off, in which the pilot flattens out after a dive, places his machine in a stalling attitude and gradually loses speed until the wheels and skid touch the ground simultaneously, the machine then slows down under the combined action of the aerodynamic and tractive resistances. During taxiing, with the machine retaining the same attitude, the aerodynamic resistance is proportional to the square of the speed. The tractive resistance is proportional to the reaction of the ground, this being proportional to the weight of the plane minus the remaining lift due to the wings.

The equation of motion is stated and elaborated mathematically, theoretical values for length of landing runs being compared with actual performance of standard airplanes in tests conducted at Roosevelt Field by the Air Mail Service and experiments made by the British Royal Aircraft Factory. Propellers and their effect on shortening landing runs are discussed mathematically and commented upon, with illustrations, and the devices for shortening landing runs are similarly considered.

The length of get-away is analyzed mathematically and the performance computations for a Curtiss HA machine are given in tabular form.

Association with the air mail-service leads me to the conclusion that the length of the landing run constitutes

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one of the greatest practical airplane problems, particularly when using the fields now available. A fast, heavily-loaded machine has excellencies of its own but is not likely to be capable of a short run; a powerfully-acting tail-skid, while giving full braking effect, is likely to damage a field and at the same time impose undue stresses upon the fuselage. In the case of forced landings, it is particularly important to have as short a landing run as possible. The mechanics of the airplane in the air have been exhaustively studied, but no mathematical considerations or conclusions are available concerning landing runs.

Considering the case of a three-point landing, with the engine shut off, in which the pilot flattens out after a dive, places his machine in a stalling attitude and gradually loses speed, until the wheels and the skid touch the ground simultaneously, the machine then slows down under the combined action of the aerodynamic and tractive resistances. During taxiing with the machine retaining the same attitude, the aerodynamic resistance is proportional to the square of the speed. The tractive resistance is proportional to the reaction of the ground, this being proportional to the weight of the plane minus the remaining lift due to the wings.

The equation of motion then becomes

$$\frac{W}{g}\int\frac{d^2x}{dt^2} = -c_1v^2 - c_3\,(W - c_2v^2), \text{ where}$$

x=the distance, measured from the landing point

W=the weight of the airplane in pounds

g=acceleration due to gravity

d=differential

t=the time in seconds

v=the velocity at any point

c_1=a constant defining the aerodynamic resistance

c_2=a constant defining the aerodynamic lift

c_3=the tractive coefficient.

$$\text{Let } \frac{g\,(c_1 - c_2c_3)}{W} = K_1, \text{ and } gc_3 = K_2$$

The equation can then be written more simply as

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$$\frac{d^2x}{dt^2} = -K_1v^2 - K_2 \text{ or}$$

$$v\left(\frac{dv}{dx}\right) = -K_1v^2 - K_2, \text{ or}$$

$$v\left(\frac{dv}{dx}\right) = -K_1\left(v^2 + \frac{K_2}{K_1}\right), \text{ therefore}$$

$$2K_1x = -\int \frac{2vdv}{v^2 + \frac{K_2}{K_1}} = -log\left(v^2 + \frac{K_2}{K_1}\right) + A.$$

When $x = 0$, $v = V_0$, where V_0 is the initial speed and

$$A = log\left(V_0^2 + \frac{K_2}{K_1}\right).$$

The length of the landing run x_l is therefore given by the expression

$$x_l = \frac{1}{2K_1}\left\{log_e \left(\frac{V_0^2 + \frac{K_2}{K_1}}{\frac{K_2}{K_1}}\right)\right\}$$

$$= \frac{1}{2k}\left\{log_e \left(\frac{K_1}{K_2}V_0^2 + 1\right)\right\}.$$

Replacing the original constants by substitution

$$x_l = \frac{W}{2g(c_1 - c_2c_3)}\left\{log_e \left[\left(\frac{c_1 - c_2c_3}{Wc_3}\right)V_0^2 + 1\right]\right\}$$

Since $c_3 V_0^2 = W$, this expression can be simplified to

$$x_l = \frac{c_3V_0^2}{2g(c_1 - c_2c_3)}\left\{log_e \frac{c_1V_0^2}{c_3W}\right\}$$

$$= \frac{\frac{c_3}{c_1}V_0^2}{2g\left(1 - \frac{c_2c_3}{c_1}\right)}\left\{log_e \frac{c_1c_3V_0^2}{c_2c_3W}\right\}$$

Writing $\frac{c_2}{c_1} = \frac{L}{D} = \frac{\text{lift}}{\text{drift}}$ at taxiing attitude, the expression becomes

$$x_l = \frac{(L/D)V_0^2}{2g[1 - (L/D)c_3]}log_e\left\{\frac{1}{(L/D)c_3}\right\}$$

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This expression clearly gives an idea as to what extent well-known factors enter in determining the length of run, and shows that this length will be longest if L/D and V_0^2 are large while c_1 is small. It also provides us with a formula from which, knowing the tractive resistance and the aerodynamic properties of the machine, the length of landing run can be determined at once. At present there appear to be few experimental data available for the verification of the above formula under conditions of service.

On May 23, 1919, a comparative test was conducted by the Air Mail Service on the Curtiss R-4-L and the Curtiss HA mail machines at Roosevelt Field, which has well-sodded ground and was in good, dry condition at the time of the test.

Data on the two machines are given in the accompanying table.

Machine	HA	R-4-L
Test load, lb.	4,018	4,200
Engine	Curtiss K-12	Liberty-12
Rated power, hp.	400	400
Wing area, sq. ft.	490.0	504.9
Wing section	Sloane	R.A.F. 6
Angle of incidence of wings to propeller thrust, deg.	0	2.5
Landing angle, deg.	16	14
Ky at landing angle	0.00246	0.00305
Landing speed, m.p.h.	56.5	52.0
Wing resistance, lb.	1,140	452
Parasite resistance, lb.	125	136
Total resistance, lb.	1,265	588
L/D at landing angle	3.15	7.15
Tractive resistance, lb.	440	500
Traction coefficient	0.104	0.119

Applying the formula previously given for the length of landing run gave values of 560 and 750 ft. respectively for the two machines. The actual test results were 539 and 711 ft. respectively. These results, even though based only upon two tests, are encouraging. It would seem that, with reasonable accuracy in the assumptions, concordance can be expected between the actual length of the run and the computed results such as are indicated.

It is interesting to review these results. A hasty consideration of the two machines might have led to the

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conclusion that the R-4-L machine, with its lower landing speed, higher tractive resistance and uglier design, would have had a much shorter landing run than that of the HA machine, whereas the latter actually had a shorter run. This can be explained only by the fact that the HA machine can be set down at a larger angle, and the wings thus furnish an enormous resistance. It is the importance of a large angle of incidence for the wings which is emphasized.

It is interesting in this respect to quote from some experiments made by the British Royal Aircraft Factory. Tests were conducted on the B.E. 2c and R.E. 7, two well-known British machines, for the purpose of finding the distance run after landing and the total space required after clearing a 6-ft. hedge.

The measurements were made by stretching a tape 6 ft. above the ground, as at *b* in Fig. 1. The pilot maneuvered the machine so as to clear this, and its height above the tape, *h*, was observed from the ground. An observer in the machine read the air speed, V_1, and then read V_2 when the wheels touched the ground. The distances *ac* and *cd* were then measured, *d* being the point directly below the propeller boss where the machine stopped. The calmest days were chosen for the experiments. The landings were made against the wind and the wind velocity was recorded.

Experiments on the B.E. 2c were repeated with an arrangement such that with the tail on the ground the angle of incidence was increased. The alteration made was to shorten the top longitudinals of the rear part of the body and thus raise the skid. The increase in the angle of incidence was 3 deg. and the total space required for landing was 20 per cent less than with the standard arrangement, the distance run after touching the ground being reduced by about 35 per cent.

The following were the average values for a good landing over a 6-ft. hedge, with no wind:

	ac	*cd*	*ad*
B.E 2c standard machine.....	200	550	750
B.E. 2c machine with tail raised....	200	400	600

No very exact data are available on the B.E. 2c machine. The B.E. 2 machine, from which it was developed, weighs 1650 lb., has a landing speed of 40 m.p. h. and a parasite resistance of 87.6 lb. at 60 m. p. h. The machine is only moderately neat in design. These fig-

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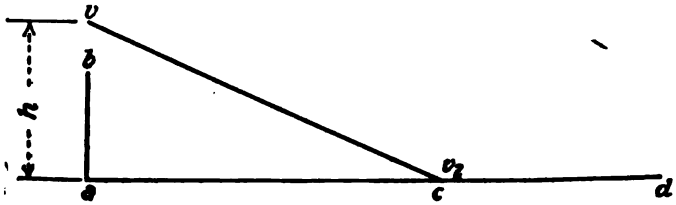

FIG. 1—DIAGRAM SHOWING DISTANCE RUN AFTER LANDING AND THE TOTAL SPACE REQUIRED TO CLEAR A 6-FT. HEDGE

ures are merely interesting as giving a general idea of the length of landing run for a smaller and slower machine.

THE PROPELLER ON A LANDING RUN

Some difference of opinion exists as to the proper method of handling the engine to insure a short run. If the speed of the engine is maintained above a given number of revolutions per minute, the propeller will continue to develop a positive thrust. If the engine can be throttled to a lower speed, the propeller may develop a negative thrust. If the engine is completely dead, and at rest, the propeller will offer resistance because of its resistance-producing area. When the engine is dead but the propeller is still revolving, the braking effect of the propeller acting as a windmill or air turbine may be important, but only when the forward speed is very great, as on a dive.

Let us consider whether any appreciable braking effect can be secured by running the engine on the ground at a very low speed, instead of completely stopping it. As an example take propeller No. 5 of Dr. W. F. Durand's report No. 14 for the National Advisory Committee for Aeronautics. Assume it to have a diameter of 9½ ft. and that it is used with a Liberty engine having a maximum speed of 1700 r.p.m. in level flight near the ground. The V/nD ratio at a speed of 110 m.p.h., which closely approximates the case of the Curtiss R-4-L machine, is $\frac{110\times1.46}{27.4\times9.5}=0.62$. In this ratio V is the airplane speed in miles per hour, n the engine speed in revolutions per minute and D the propeller diameter in feet. The thrust coefficient from Plate VI in Dr. Durand's report is 0.55 and the thrust is given by the formula

$$T=\frac{T_c D^2 V^2 \Delta}{100}, \text{ where}$$

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$\Delta = 0.0761$, the density of the air.

Applying the formula

$$T = \frac{0.55 \times (9.5)^2 \times (160)^2 \times 0.0761}{100} = 965 \text{ lb.}$$

The torque coefficient is 0.78 so that the torque is

$$Q = \frac{Q_o D^5 V^2 \Delta}{1000}$$

$$= \frac{0.78 \times (9.5)^5 \times (160)^2 \times 0.0761}{1000}$$

$$= 1270 \text{ lb.-ft.}$$

The power under the above conditions is 410 hp., which the Liberty engine can just develop. The efficiency is 69 per cent, showing that the propeller would be fairly suitable for the R-4-L Curtiss machine.

In the National Advisory Committee's Report No. 30, results are given for the same propeller at negative thrust for very high values of V/nD. Suppose we consider 52 m.p.h. the landing speed of the R-4-L machine. The negative thrust as given by the formula is

$$\frac{\text{(Brake-effect coefficient)} \ \Delta \ D^2 V^2}{100}$$

and its maximum value occurs at a value of V/nD of approximately 1.8 when the brake-effect coefficient has a maximum value of 0.46. The engine speed for this value of V/nD must be 270 r.p.m. and the thrust will be

$$\frac{0.46 \times (9.5)^2 \times (76)^2 \times 0.0761}{100} = 182 \text{ lb.}$$

No power curves are given for the test and the objection might be made that to produce this negative thrust, the Liberty engine would have to develop more power than it can deliver at 270 r.p.m. The negative thrust as thus developed is only equivalent to 24 hp., however, and if the V/nD ratio were decreased to 1.2 by increasing the engine speed to 405 r.p.m., the negative thrust would still be 127 lb.

The Durand propeller No. 5 was selected quite at random, and yet the maximum possible thrust is found to be 182 lb. for the landing speed of the R-4-L machine. Since this is about 40 lb. more than the skid drag of the same machine, it is by no means negligible but this propeller is not a very good illustration of what it is possible to do

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with a propeller in the region of negative thrust. In the curves of Fig. 2, taken from Plate XXX of Report No. 30, it is seen that the brake-effect coefficient at its maximum is not so very much greater than the approximately asymptotic value of the coefficient, at very high values of V/nD when the number of revolutions per minute become very small. With such a propeller, the maximum brake-effect coefficient would therefore not be so very much greater than if the propeller were not revolving, and thus opposing forward motion simply by virtue of its resistance area.

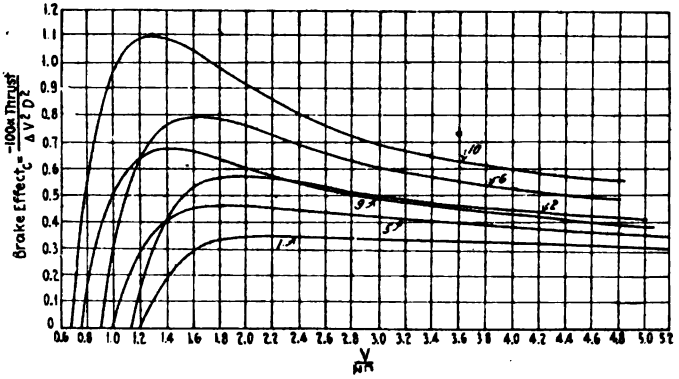

FIG. 2—BRAKE-EFFECT COEFFICIENT CURVES

But the brake-effect coefficient of propeller No. 10, as indicated in the same series of curves, is more than twice as great as that of propeller No. 5, and at an airplane speed of 52 m.p.h., a V/nD ratio of 1.2 and engine speed of 410 r.p.m., would, with the same propeller diameter of 9½ ft., give a negative thrust of 400 lb., which would check the landing run very rapidly. Moreover, propeller No. 10 has a maximum brake-effect coefficient much greater than the values shown on the curves for very large values of V/nD and approaching the condition of a non-revolving propeller.

The investigation of Report No. 30 indicates that for a given size of propeller, wide blades have a larger brake effect than narrow blades, and that the brake effect of the higher-pitch propeller is less than that of the lower-pitch propeller. The latter result is quite reasonable as can be seen from the diagrammatic representation in Fig. 3, since with a low-pitch propeller the tendency will

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be for the air to strike the propeller blade element at a larger negative angle to the chord.

An objection might be made that as the landing run proceeded and V decreased, the V/nD ratio would decrease so that the pilot would run the propeller into a region of low brake-effect coefficient, or even of positive thrust, and it is quite possible that pilots may at first find considerable difficulty in getting the best braking effect. But with a broad-blade, low-pitch propeller, it seems clearly evident that pilots would find an advantage in experimenting on their landing run until they found the best possible combination. The shortening of the landing run resulting therefrom might make all the difference between a poor and a good commercial machine.

Devices for Shortening Landing Runs

The most obvious device for shortening a landing run is the use of an airbrake consisting of flat plates hinged at the sides of the fuselage. To avoid the effort which is required to operate such brakes, it is advisable to have the plates arranged so that the relative wind will force the side plates to open while the opening of the under flap is retarded by the wind. A fairly simple arrangement for the control of such an airbrake is shown in Fig. 4. This type of brake has been used on British machines, but objections can be raised to its employment on the grounds of complication and also that the resistance of the brakes diminishes rapidly as the speed decreases.

In a British test, the model body RE-1, shown in Fig. 5, had a length of 25½ in. or one-twelfth of the full size, and a brake area of approximately 0.0358 sq. ft. In a 40-ft. per sec. wind, the increase in drift due to a 90-deg. opening of the brakes was 0.0804 lb., giving a brake-effect coefficient of 0.003 per sq. ft. per m.p.h. This indicates that airbrakes will offer practically the same resistance as flat plates freely exposed.

The full-size area of the brakes for the RE-1 is 5.15 sq. ft. Imagine brakes of 10-sq. ft. area applied to the Curtiss R-4-L machine, whose landing run has been previously discussed and which is a larger machine than the RE-1. The resistance at 52 m.p.h. will be 81.5 lb. and the L/D ratio becomes 6.3. The calculated run now becomes 680 ft. instead of the 750 ft. previously computed. It is quite clear from this that the effect of airbrakes is

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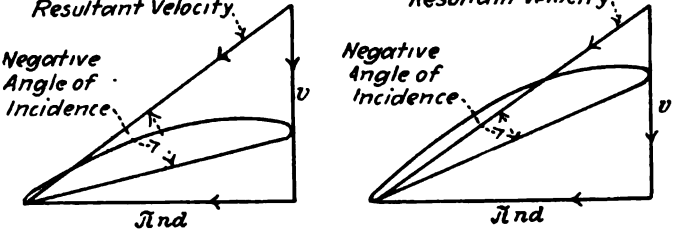
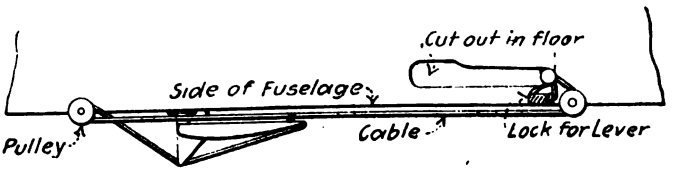


FIG. 3—DIAGRAMS TO ILLUSTRATE THE GREATER EFFECTIVENESS OF LOW-PITCH PROPELLERS AS A BRAKE

small, and hardly worth inclusion. On a very small machine it is possible that brakes of a large size relative to the wing area might be included with more satisfactory results.

While airbrakes may be set aside as entirely unpromising, the use of wing flaps extending over almost the entire trailing edge is worthy of the most serious consideration. This device has been used successfully in a



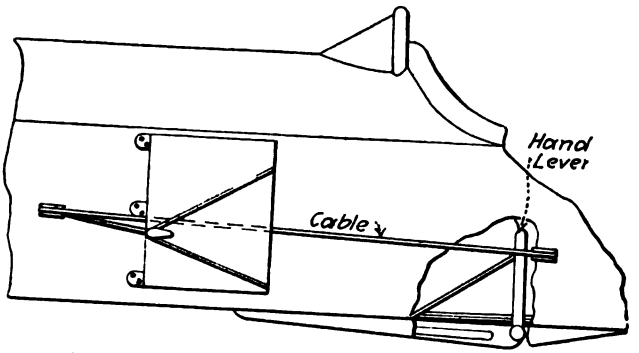


FIG. 4—AN AIRBRAKE CONTROL ARRANGEMENT

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Sopwith 110 Clerget single-seat seaplane and in a seaplane built by the Fairey Aviation Co. A diagrammatic scheme for a proposed employment of wing flaps without disturbing the functions of the ailerons is shown in Fig. 6.

In some British experiments carried out on an R.A.F.9 wing section with the hinged rear portion occurring at 0.385 of the chord, the maximum lift obtainable was in-

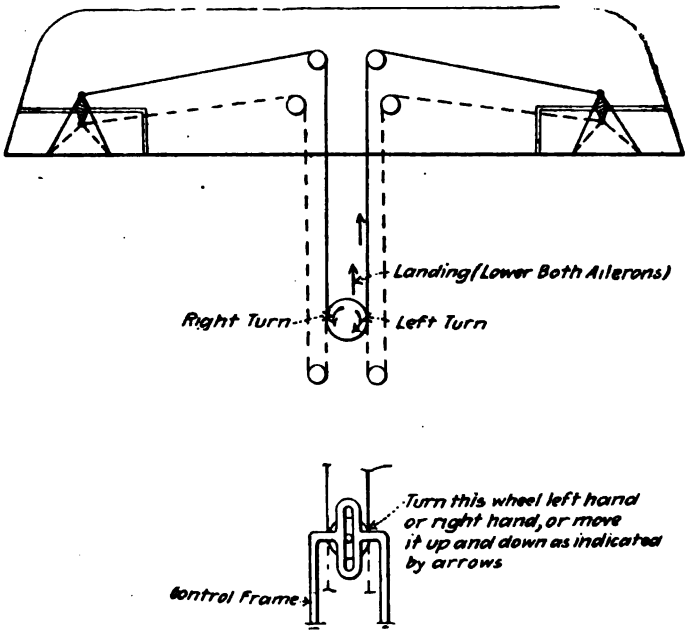
Landing (Lower Both Ailerons)
Right Turn
Left Turn
Turn this wheel left hand or right hand, or move it up and down as indicated by arrows
Control Frame

FIG. 5—MODEL OF AN RE-1 BODY

creased in the ratio of 1.35 to 1, the flap being set at 60 deg. to the wing. This maximum lift occurs when the angle of incidence of the wing proper is in the neighborhood of 4 to 6 deg. Such an increase in the maximum lift would decrease the landing speed in the ratio of 1 to 0.865. If the flap were used intelligently by the pilot, it could be used effectively as a brake, after the machine had settled at a speed and attitude corresponding to the maximum lift, by being set at a maximum pitch of 90 deg. to the wing, with the wing itself at an attitude cor-

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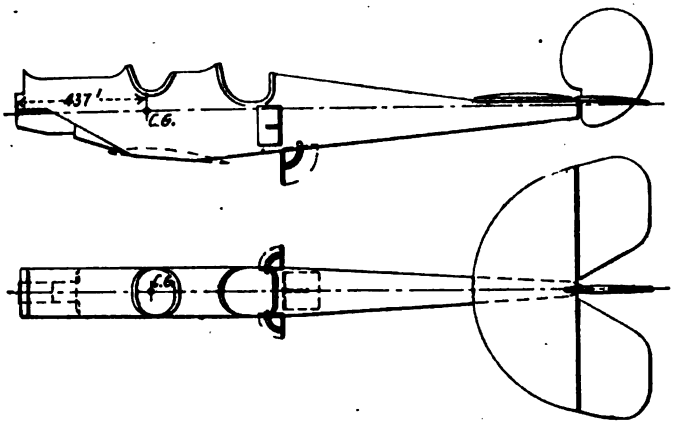

FIG. 6—PROPOSED ARRANGEMENT TO EMPLOY WING FLAPS

responding to a three-point landing. Even when the flap was only set at a 45-deg. positive angle to the wing, the drift of the R.A.F.9 at 14 deg. was increased in the ratio of 5.45 to 1.

If the mechanism were applied to the Curtiss R-4-L machine and used as already explained, with flap set at

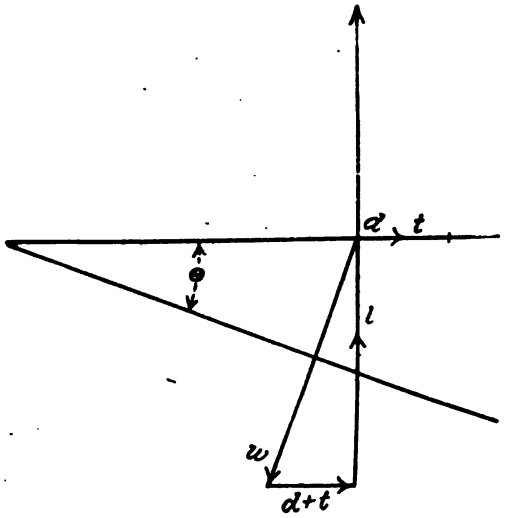

FIG. 7—SYSTEM OF FORCES ON A GLIDE WITH NEGATIVE PROPELLER THRUST

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a positive 60-deg. angle for landing and a positive 90-deg. angle for braking, the landing speed would become 45 m.p.h. and the landing run would be reduced to about 200 ft., as compared with the 750 ft. previously computed. A definite conclusion would be that wing flaps extending along the rear edge would be of very appreciable help.

It is very often assumed that a variable-pitch propeller will decrease the landing speed by imposing a large negative thrust on the airplane in the dive. A short consideration of the problem will indicate that this conception is erroneous. Consider Fig. 7, where t represents the negative propeller thrust. The equations of equilibrium are

$$l = w \cos \Theta = K_y A V^2$$

$$w \sin \Theta = (K_x + K_p) A V^2 + t$$

$$\tan \Theta = \frac{K_x + K_p}{K_y} + \frac{t}{K_y A V^2}, \text{ where}$$

l = lift

w = weight

Θ = angle of flight

K_y = lift coefficient

K_x = wing-drag coefficient

K_p = parasite resistance coefficient

V = velocity

A = lifting area

t = thrust

For small angles of glide, where cos Θ is close to unity, the effect of a negative propeller thrust will be simply to increase Θ for any speed of glide of the machine. It is only on a very steep, almost vertical, dive that the negative thrust will act usefully by keeping down the terminal velocity. On recovery from the dive, the negative propeller thrust will have no effect upon the landing speed, which will always be defined by the maximum K_y of the plane. The variable-pitch propeller will, however, have a very powerful effect indeed on the landing run and will be probably the most efficacious method of braking possible.

In Fig. 8, the forward skid arrangements for the

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English Avro and the Ace machines are shown. Such arrangements are equivalent to the placing of an extra tail-skid and an extra tractive effect, without the inconveniences entailed in carrying the center of gravity far

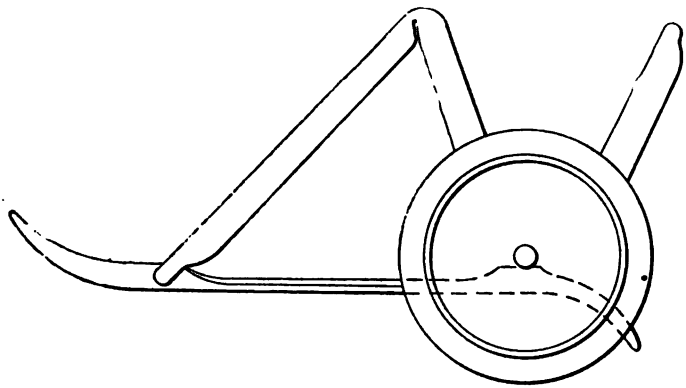

FIG. 8—FORWARD SKID ARRANGEMENTS FOR THE AVRO AND ACE AIRPLANES

behind the wheels, which means difficulties in get-away and a damaging effect on the field due to an extremely heavy tail-skid load. If, in the Curtiss R-4-L machine, the skid tractive effect of 140 lb. were increased to 280 lb. by the use of a forward skid, the computed run would be shortened to 615 ft. instead of 750 ft., which is an appreciable difference.

Brakes on wheels have been avoided hitherto because of the tendency induced of nosing the machine over, but with a small forward wheel or skid they might become a very useful device.

LENGTH OF GET-AWAY

It is much more difficult to arrive at an exact determination of the length of the get-away run owing to the fact that the attitude of the machine may change during the run, and also because the thrust of the propeller varies during the run. For every machine there is undoubtedly a best attitude for the get-away and a best method for attaining the quickest get-away. In the comparative test of the Curtiss HA and R-4-L machines previously mentioned, the tractive resistances were

	HA	R-4-L
With tail-skid dragging, lb.	440	500
With tail-skid set in a two-wheel truck, lb.	240	360

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This indicates quite clearly that the pilot should get the skid off the ground as soon as possible and thereby remove a considerable portion of the tractive effort. Unless the center of gravity is very far back of the wheels, this should be possible almost as soon as the engine is fully effective and the slipstream of the propeller hits the tail surfaces.

When the plane starts off, the equation of motion becomes

$$\frac{Wd^2x}{gdt^2} = t - cV^2 - c_3(W - c_1v^2),$$

The notation is the same as that previously employed and t is the thrust of the propeller. The resistance to movement can be expressed by the formula

$$(c_1 - c_2c_3)\, v^2 + c_3W.$$

Since c_3W is a constant, the acceleration will be a maximum when $(c_1 - c_2c_3)$ is a minimum. To find the attitude at which this is a minimum, graphical methods are best employed. Taking the HA machine for which the tractive coefficient without skid drag is 0.06, the Curtiss Company's performance computations for a load of 3994 lb. are given in the accompanying table.

Plotting the curve in Fig. 9, it is seen that the minimum value of $c_1 - c_2c_3$ occurs in the neighborhood of 4 deg., at which also occurs the best L/D ratio for the machine. This is what might be expected on general grounds. With the skid off the ground, the tractive coefficient is so low that it will not pay to reduce the reaction on the ground by lifting on the wings. At the same time, if the machine were taken off at too small an angle, the L/D ratio of the wings would be too low.

An investigation of the R-4-L machine figures gives a similar result. The computations indicate as correct on theoretical grounds the procedure adopted in a get-away by the best pilots, namely, a quick lifting of the tail and a subsequent run at a small angle of incidence until the flying speed is attained.

The design of the propeller has a certain influence on the length of get-away, although it is difficult to reconcile a propeller working efficiently on the get-away with satisfactory performance in speed and climb. The broad

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PERFORMANCE COMPUTATIONS OF CURTISS HA MACHINE

Speed, m.p.h.	57.5	60	70	80	100	120	125
Angle of incidence, deg.	16.0	12.2	7.5	5.1	2.6	1.3	1.0
Ky for 1 m.p.h. per sq. ft.	0.002460	0.002260	0.001664	0.001274	0.000815	0.000566	0.000522
Wing resistance, lb.	1,140	726	307	247	250	294	307
Parasite resistance, lb.	125	126	162	210	326	469	509
Total resistance, lb.	1,265	852	469	457	576	763	816
c_1 in ft. per sec. units	0.18100	0.10900	0.04420	0.03300	0.02670	0.02460	0.02420
c_2 in ft. per sec. units	0.56200	0.51500	0.37800	0.29000	0.18500	0.12750	0.11800
$c:c_2$	0.03360	0.03080	0.02260	0.01740	0.01110	0.00765	0.00710
$c_1 - c_2 c_2$	0.14740	0.07820	0.02160	0.01560	0.01560	0.01695	0.01710

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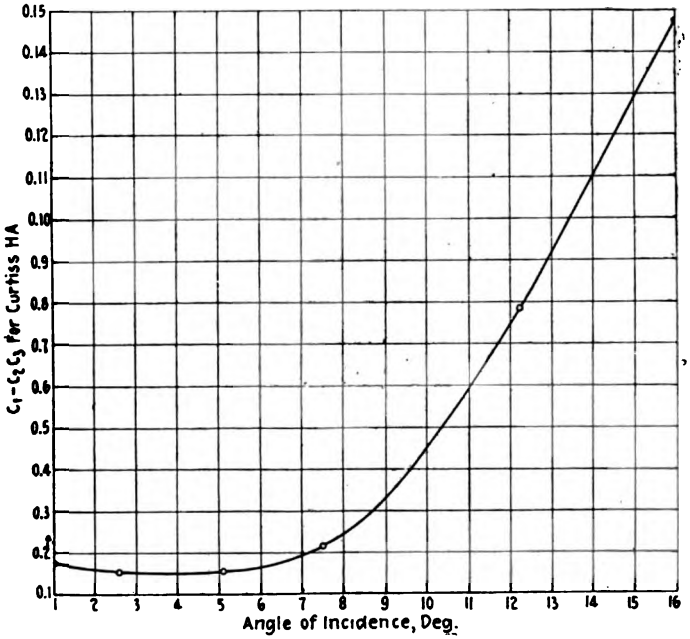

FIG. 9—CURVE OF c_1-c_2 c_3 FOR A CURTISS HA AIRPLANE PLOTTED AGAINST THE ANGLE OF INCIDENCE

rule for a quick-get-away propeller is to have the diameter small enough so that the engine can attain as high a number of revolutions per minute on the ground as possible, as the thrust increases rapidly with the speed of revolution. Propellers of smaller pitch generally have the larger thrust-power ratio, and wide-blade propellers generally have larger thrust-power ratios also, as indicated in Dr. Durand's tests.

The variable-pitch propeller will be of great value in securing a speedy get-away, since the pitch can be made small on the ground, while in level flight it can be made suitably high. Much practical and theoretical work remains to be done before the full possibilities of the variable-pitch propeller can be realized.

No attempt has been made in the course of this paper to compute the length of get-away. To do this, it would be necessary to know the characteristics of the propeller at low ratios of V/nD and at static thrust, and either to solve the equation of motion by integration for the intervals during which the propeller thrust would be constant, or by putting the thrust into the equation as

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a function of the velocity. I hope to work out this problem for a typical machine at a later date. The question of the length of get-away offers less difficulty in commercial flying than the landing run, since for the get-away there can be a better selection of ground. In the comparative test on the HA and R-4-L machines, the get-away distances were 538 ft. for the HA and 524 ft. for the R-4-L machine. On the landing run the HA machine was better, owing to the larger angle of incidence that could be maintained in rolling on the ground, but the R-4-L machine made a quicker and shorter get-away because of its lower minimum flying speed.

ENGINE SHAPE AS AFFECTING AIRPLANE OPERATION

By Grover C Loening[1]

The annual report covering transportation by the largest British air-transport company laid particular emphasis upon the greater value of the faster machines in its service. Granted that efficient loads can be carried, the expense, trouble and danger of the airplane are justified only when a load is carried at far greater speed than by any other means. A reasonable conclusion seems to be that we can judge the progress made in aviation largely by the increased speed attainable. It is interesting and possibly very valuable therefore to inquire into the relations of power and resistance as applied to small racing machines with aircraft engines that are available.

The engine builder is only too likely to think that he has reached the goal required by the aircraft builder if he can make the light-weight figure of the engine "dry," in pounds per horsepower, low enough, but this attitude is not only erroneous but actually tends to the development for aircraft of engines that are very undesirable. Four specific and reasonable, although admittedly not absolutely correct assumptions, are made and, after analysis, they are stated to mean that engines are not penalized by placing them in different

[1]Loening Aeronautical Engineering Corporation, New York City.

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types of aircraft and that the consideration of the figures on a unit horsepower basis is justified. The radiator and wing drift are discussed, with accompanying tables of the sizes of various well-placed radiators and of the air-resistance characteristics of engines, and photographs of various types of engine. The subject of resistance coefficients is treated at some length and followed by an explanation of and comment upon a speed-resistance chart which is presented. The author states that resistance is more important than weight and urges builders to make the shape and disposition of their engines more suitable for airplanes, with low head resistance considered as a fundamental.

It is generally accepted that speed is the *raison d'être* of the airplane, particularly as proved in the passenger air services maintained in Europe between London, Paris Brussels, and other places. The annual report covering transportation by the largest British air-transport company, Airco, laid particular emphasis upon the greater value of the faster machines in its service. Granted that efficient loads can be carried, the expense, trouble and danger of the airplane are justified only when a load is carried at far greater speed than by any other means. That we may judge the progress made in aviation year by year largely by the increased speed attainable, seems to be a reasonable conclusion. Although this high speed is always first attained by small special racing machines, the history of aviation has shown that the same high speed is soon attained by machines carrying a more practical load.

Principally in connection with the coming Gordon Bennett International Air Race, much has been heard of late of the probability of 200 m.p.h. being attained in racing. The Nieuport single-seater, with an especially small wing area, is credited with about 190 m.p.h., although this machine in a closed circuit averaged about 170 m.p.h. It is interesting and possibly very valuable, therefore, to inquire into the relations of *power* and *resistance* as applied to small racing machines with aircraft engines that are available today.

One might crystallize the general off-hand sentiment of the aviation world with regard to fast machines by pointing out that the light-weight high-powered radial air-cooled engines are generally considered the coming type for small fast aircraft; while the large heavy high-powered water-cooled engines are generally placed in large slow load-carrying airplanes. Further than this,

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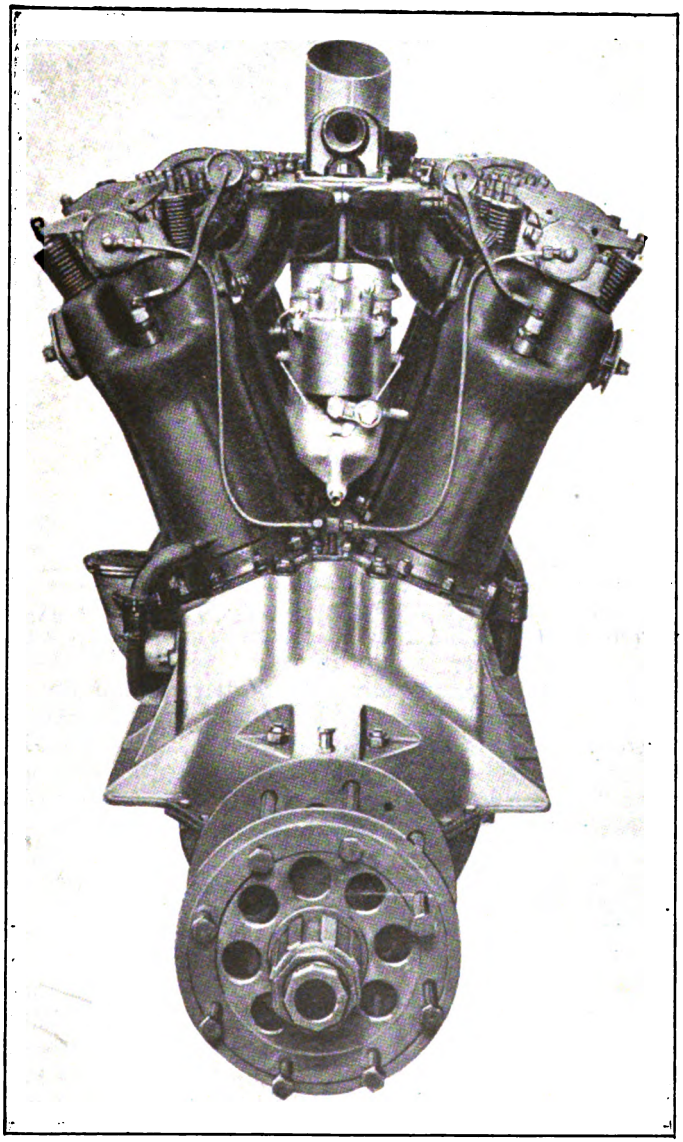

THE TWELVE-CYLINDER LIBERTY ENGINE

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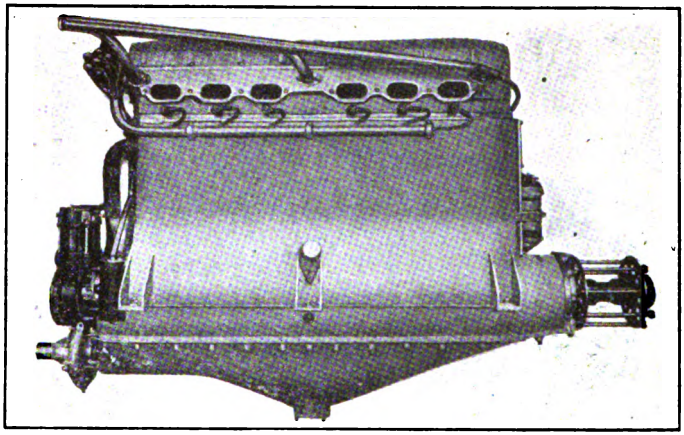

THE AEROMARINE SIX-CYLINDER ENGINE

there is a distinct tendency on the part of engine builders to sacrifice some details for the purpose of lightening the weight of the engines, so that they can place in their catalogs an extravagant figure stating the light weight of the engine, "dry," in pounds per horsepower. The engine builder is only too likely to think that he has reached the goal required by the aircraft builder if he can make this figure low enough. In this paper, however, it is proposed to demonstrate that this attitude is not only erroneous, but actually tends to the development for aircraft of engines that are very undesirable for several important reasons.

Leaving for a moment consideration of fast aircraft from the airplane standpoint, we can consider when all is said and done that the airplane engine must drive itself through the air, and requires some proportion of wing area to carry its own weight. Considering the power absorbed by the engine itself, we find that it consists of the head resistance of the engine and of its necessary water or oil radiators, due to their shape, and the drift on the wings that is chargeable to the weight of this powerplant. To separate these two items and examine into the desirability of various engines for the attainment of high speeds, we must analyze the cost of head resistance due to a heavy engine as against a light engine, and add the cost of head resistance caused by a bulky or a streamlined engine as the case may be.

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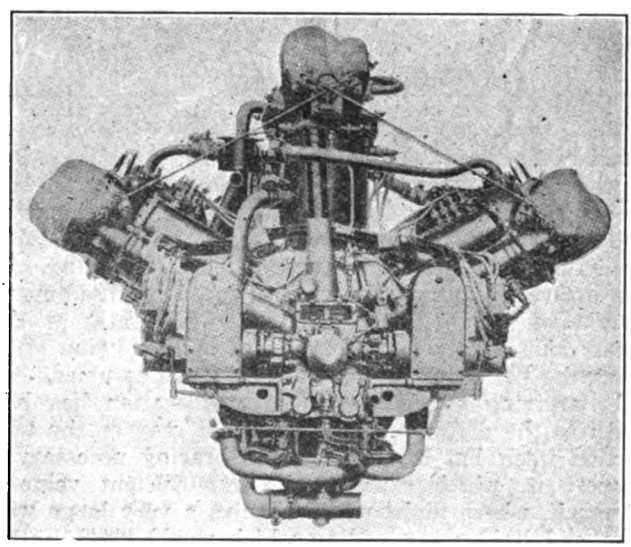
Let us simplify this problem by making the following reasonable, although admittedly not absolutely correct, assumptions:

(1) In high-powered, carefully-designed aircraft engines, the fuel consumption per horsepower is very nearly the same
(2) In applying maximum skill in airplane design, it is likely that the weight per horsepower of the airplane structure necessary to carry any of these engines will be about the same
(3) The propeller efficiency of the various engines can be considered practically the same, because we are examining primarily the high-speed conditions where the advantage of the slow speed of the geared propeller does not enter and might even prove detrimental
(4) In the drift of the wings necessary to carry any engine, the same lift/drift ratio can be assumed

It will be found on analyzing these assumptions that they mean that we do not penalize engines by placing them in different types of aircraft, and are thus justified in considering figures on a unit horsepower basis.

The Radiator and Wing Drift

It has been found quite conclusively on many types of aircraft using water-cooled engines that, no matter



The Napier Lion Engine

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where the radiator is placed, a certain amount of head resistance must be expended to get cooling, since the air must pass through the radiator. Placing the radiator in front of an engine, in an effort to combine the resistance of the two, merely makes it necessary to add to the size of the radiator by exactly the amount that the presence of the engine behind it blocks circulation. This is particularly true of the Liberty engine when mounted on the De Haviland-Four. Good practice dictates that we separate the radiator resistance from that of the engine itself, and assign to the necessary size of radiator a reasonable frontal area in square inches per horsepower, varying with the speed.

A review of the sizes of various well-placed radiators gives the values for frontal areas presented in Table 1.

This reduction in the size of radiator, of course, involves the consideration that on a high-speed machine the radiator be retractable.

TABLE 1

Speed, m.p.h.	Frontal Area of Radiator, per Horsepower sq. in.	Lift/Drift Ratio
50	2.5	1 to 8
100	2.0	1 to 11
150	1.5	1 to 11
200	1.0	1 to 10

The weights of the engines shown in Table 2 are inclusive of radiator, water and propeller, complete. Part of the airplane's wing area must do its share of work in supporting the weight of the engine, and this work will cost a certain amount in head resistance represented by the drift of this proportion of the wing. We can arrive at this figure for any speed by dividing the weight of the engine by the lift/drift ratio at that speed, and from an examination of efficient wing structures the lift/drift ratios in Table 1 are assumed.

In arriving at these values consideration has been given to the drift as a resistance not only of the wing section itself but of the complete bracing necessary to support it, which explains the less efficient value at 50 m.p.h. where flight would require a very large wing area and light wing-loading which would necessitate a high head resistance in struts and wires.

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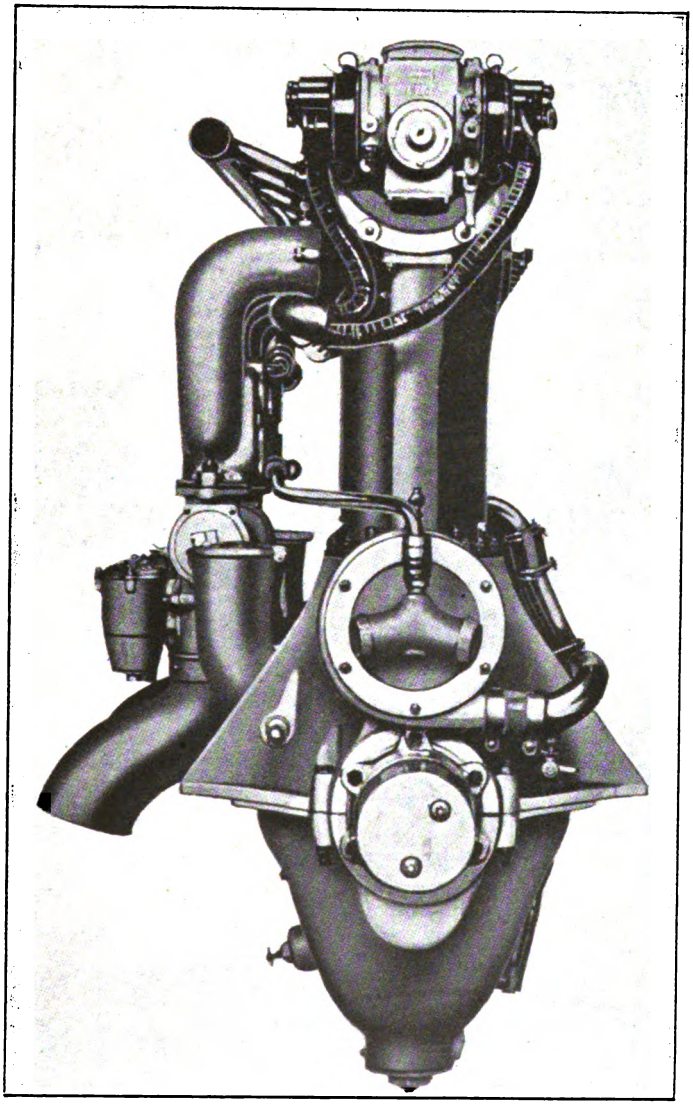

THE HALL-SCOTT L-6 ENGINE

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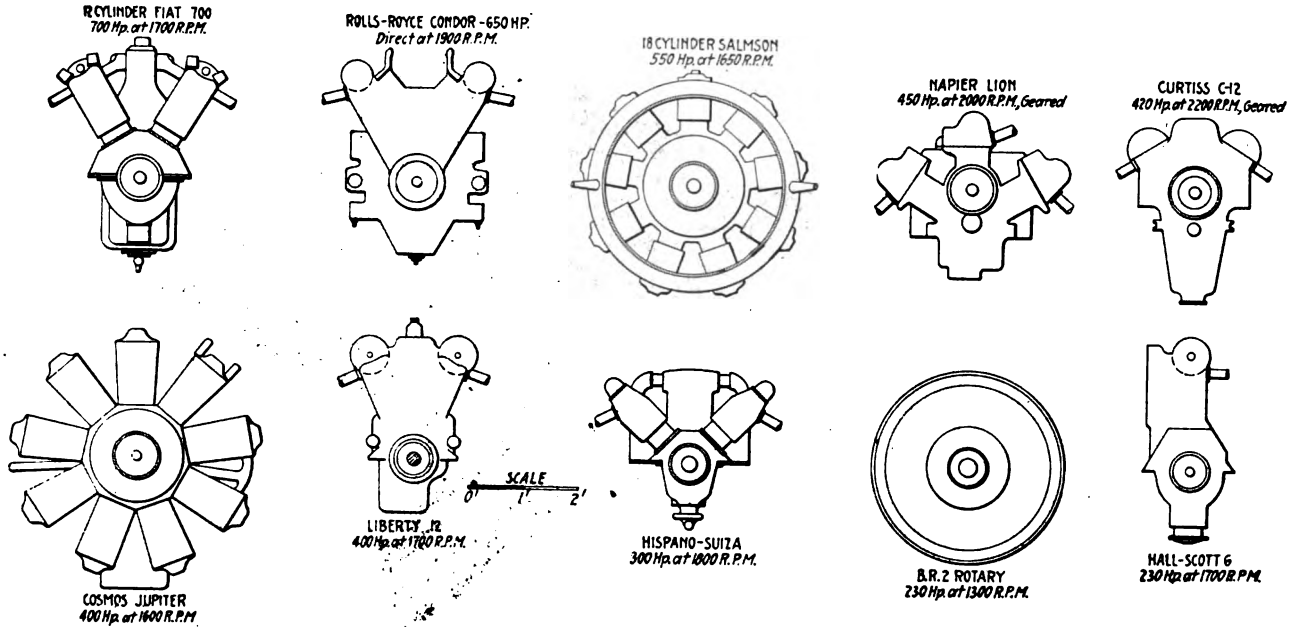
12 CYLINDER FIAT 700
700 Hp. at 1700 R.P.M.
ROLLS-ROYCE CONDOR - 650 H.P.
Direct at 1900 R.P.M.
18 CYLINDER SALMSON
550 Hp. at 1650 R.P.M.
NAPIER LION
450 Hp. at 2000 R.P.M., Geared
CURTISS C-12
420 Hp. at 2200 R.P.M., Geared
COSMOS JUPITER
400 Hp. at 1600 R.P.M.
LIBERTY 12
400 Hp. at 1700 R.P.M.
SCALE
0 1' 2'
HISPANO-SUIZA
300 Hp. at 1800 R.P.M.
B.R.2 ROTARY
230 Hp. at 1300 R.P.M.
HALL-SCOTT 6
230 Hp. at 1700 R.P.M.

TABLE 2—AIR-RESISTANCE CHARACTERISTICS OF ENGINES

Name	Power hp.	Number of Cylinders	Weight with Radiator, Water and Propeller, lb.	Weight, lb. per hp.	Frontal Area, sq.ft.	50 m. p. h.						100 m. p. h.						150 m. p. h.						200 m. p. h.					
						Engine Resistance, lb.	Radiator Area, sq. ft.[6]	Radiator Resistance, lb.	Wing Drift Resistance, lb.	Total Resistance, lb.	Resistance per hp., lb.	Engine Resistance, lb.	Radiator Area, sq. ft.[6]	Radiator Resistance, lb.	Wing Drift Resistance, lb.	Total Resistance, lb.	Resistance per hp., lb.	Engine Resistance, lb.	Radiator Area, sq. ft.[6]	Radiator Resistance, lb.	Wing Drift Resistance, lb.	Total Resistance, lb.	Resistance per hp., lb.	Engine Resistance, lb.	Radiator Area, sq. ft.[6]	Radiator Resistance, lb.	Wing Drift Resistance, lb.	Total Resistance, lb.	Resistance per hp., lb.
Fiat[2]	700	12	1,970	2.82	6.22	14.0	12.0	36.0	246	296	.42	56	9.7	116	180	352	0.50	126	7.3	197	180	503	0.72	224	4.9	235	197	656	0.94
Rolls-Royce Condor[3]	650	12	1,400	2.16	7.32	16.5	11.3	34.0	175	225	0.35	66	9.1	109	127	302	0.47	148	6.8	184	127	459	0.71	264	4.7	226	140	630	0.97
Salmson[4]	550	18	1,120	2.04	10.10	22.5	9.5	28.5	140	191	0.35	91	7.6	91	102	284	0.51	204	5.7	154	102	460	0.84	362	3.8	182	112	656	1.20
Napier Lion	450	12	1,040	2.30	5.68	12.8	7.8	23.5	130	166	0.37	51	6.2	75	94	220	0.49	115	4.7	127	94	336	0.75	204	3.1	149	104	457	1.02
Curtiss C-12	420	12	830	1.97	4.66	10.5	7.3	22.0	103	136	0.32	42	5.8	69	75	186	0.44	94	4.4	119	75	288	0.69	168	2.9	139	83	390	0.93
Cosmos-Jupiter[5]	400	9	690	1.73	12.65	28.3	...	...	86	114	0.28	114	...	...	63	177	0.44	256	...	...	63	319	0.80	458	...	...	69	527	1.32
Liberty	400	12	1,090	2.74	5.16	11.6	7.0	21.0	136	169	0.42	47	5.6	67	99	213	0.53	105	4.2	104	99	308	0.77	186	2.8	135	109	430	1.08
Hispano-Suiza	300	8	810	2.69	4.75	10.7	5.2	15.6	102	148	0.49	43	4.2	51	73	167	0.55	96	3.2	86	73	255	0.85	171	2.1	101	81	353	1.17
BR-2	230	9	530	2.30	9.62	21.7	...	...	66	88	0.37	87	...	...	48	135	0.59	195	...	...	48	243	1.05	346	...	...	53	399	1.73
Fall-Scott, L-6	230	6	630	2.75	3.87	8.7	4.0	12.0	79	100	0.43	35	3.2	38	57	130	0.56	78	2.4	65	57	200	0.87	139	1.6	77	63	279	1.21

[2]Direct drive
[3]Direct drive for high speed
[4]Water-cooled; radial.
[5]Air-cooled: radial
[6]The value of the frontal area of the radiator in square inches per horsepower developed by the engine for the different speeds and the lift-drift ratio or drift resistance are given in Table 1.

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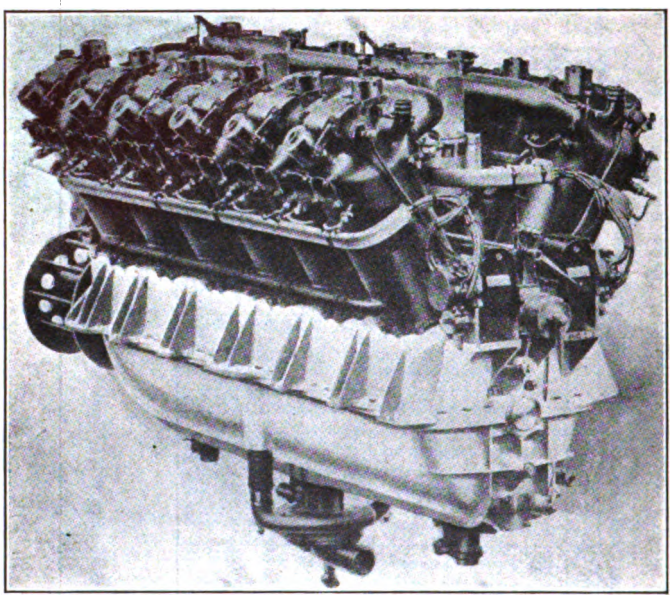

THE 700-HP. FIAT ENGINE

RESISTANCE COEFFICIENTS

The resistances of various fuselages measured in wind tunnels have been reviewed and found to differ considerably from the actual resistance of fuselages of full-size airplanes, as determined from their actual performances. This is probably due to the ignoring of the slipstream effect. At any rate, a review of all these figures indicates that in the formula $R = KSV^2$ the value of the resistance coefficient K, for most fuselages, averages about 0.0009, where cross-sectional area is expressed in square feet and the speed V in miles per hour. This value has been adopted for all engines, a reasonable assumption if one desires to obtain a better-shaped body by making the fuselage larger at one-third of its distance back from the engine, inasmuch as the resistance of the larger cross-sectional area very nearly balances the lower resistance coefficient.

An examination of the resistance coefficients of radiators discloses the fact that when the resistance of the headers and some piping is included, the coefficient K for radiators of the best shapes is at least 0.0012, where

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the frontal area of the radiator S is expressed in square feet and the air speed in miles per hour. New types of radiators, such as the Lamblin circular radiator, will modify this slightly, primarily because of the more efficient shape of the header arrangement; although, as pointed out by Colonel Bristow in an excellent article[7] on aircraft engines at the Paris Show, the amount of piping necessary to connect up this radiator probably would rob it of much of its advantage.

With the above data it becomes possible to establish a new quantity, the resistance per horsepower of the engine. How much more important this new quantity is than the quantity weight per horsepower of the engine, to which we have been giving so much attention, will readily be shown by a further examination of the various engines. Table 2 shows the characteristics of the engines which are representative of the latest developments.

This table shows the weight per horsepower of these engines complete, including the radiator, water, propeller, etc. At speeds of 50, 100, 150 and 200 m.p.h., values are given for the frontal area of the radiator, and the radiator, engine and drift resistances due to the weight of the engine, all of which are finally summed up to determine the total resistance in pounds per horsepower due to the shape, weight and type of engine.

The Speed-Resistance Chart

The values derived from the table have been plotted on a chart in which the abscissas are speeds in miles per hour and the ordinates the total air resistance of the engine due to its shape and its weight as carried by the wing, expressed in pounds per horsepower. In a rather striking manner the chart brings out figures that are perhaps worthy of consideration by every engine builder and designer interested in developing higher speeds. The general opinion as to aircraft engines held by the aviation world is subject to considerable correction, for we find that the best engine for a heavy load-carrying machine at slow speeds is the Cosmos Jupiter, the latest air-cooled radial type; and the best engine for high speeds is the heavy, high-powered, water-cooled engine represented by the 700-hp. Fiat. Close to this we find the beautifully-shaped Curtiss C-12.

[7]See *Aircraft Engineering*, January, 1920.

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At about 100 m.p.h. all of the types of engine considered have very nearly the same air resistance. At 250 m.p.h., to which speed the chart has been carried, the differences are clear. The general quantitative picture presented by this chart shows us that the light air-cooled radial type, with a high head resistance, loses the value of its light weight as soon as its poor shape begins to absorb more of its power in resistance. The difficulty of getting high speeds out of rotary engines, for example, is obvious when it is realized that at speeds of only 80 m.p.h. the BR-2 rotary engine begins to become very much less efficient than the six-cylinder Hall-Scott engine of about the same horsepower.

To determine what high speeds the present available engines would permit under ideal conditions, we can lay off on the chart a curve showing the allowable resistance per horsepower. This forms a barrier beyond which we cannot go, simply because 1 hp. is itself entirely consumed by the allowable resistance. The values on the chart show the resistance per horsepower of the engine. Considering a high-speed airplane with practically no structural resistance other than that of the engine and the fuselage behind it, and with a landing gear practically eliminated as a resistance by being retracted, we could estimate that a load of fuel, the pilot and the airplane structure itself, would consume in the form of drift on the remainder of the wing area not already carrying the engine, about 25 per cent of the total available power. Thus 75 per cent of each horsepower in the engine is available to combat the engine's resistance and will permit this engine resistance to rise up to the figure that uses up the allowable pounds. Thus we arrive at a curve from the formula

$$\frac{\text{Horsepower} \times 375}{\text{Speed in miles per hour}} \times 0.75 = \text{Maximum allowable resistance in pounds.}$$

From this curve we can conclude that under ideal conditions, with reasonable extremes in design for the racing machine, we could obtain a high speed of 235 m.p.h. with the Fiat, 232 with the Curtiss C-12, gradually working down to 204 for the Cosmos, and 180 for the BR-2 rotary engine. It is seen, therefore, putting consideration of landing speed aside, that straightaway speeds of 200 m.p.h. are distinctly possible. Of course, in a small circuit, the maneuvering ability of the machine would greatly modify this.

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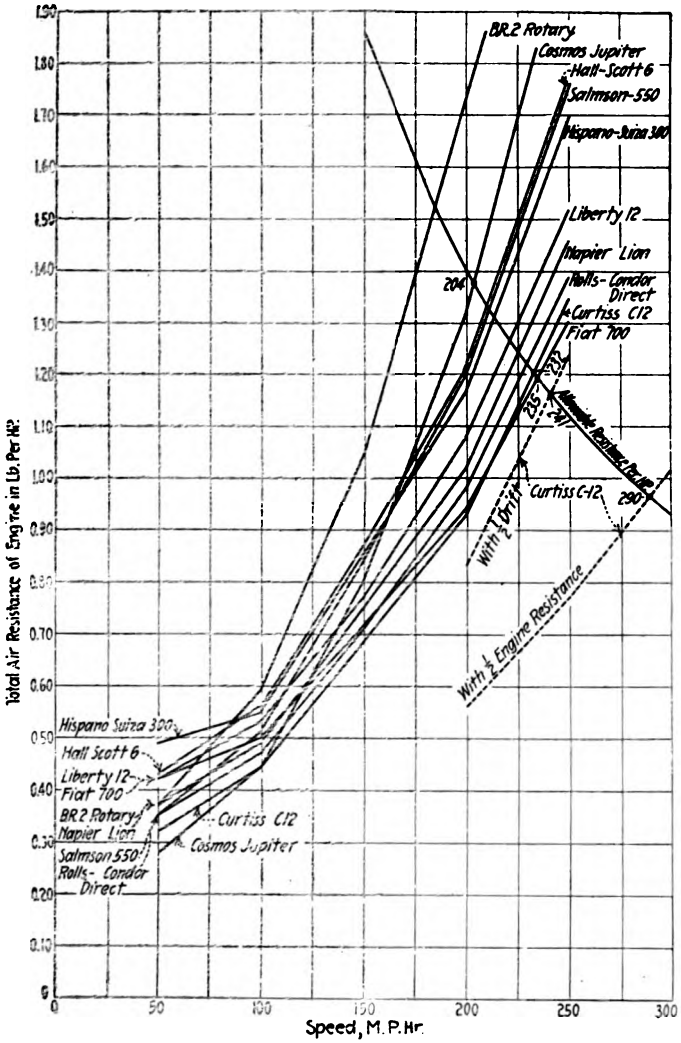

SPEED-RESISTANCE CHART

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Resistance More Important than Weight

The chart permits an interesting demonstration when we take the figures for the Curtiss C-12 and assume first that by laborious work the weight of the engine is reduced to one-half its amount, which it is very doubtful could ever even be approached in this type of engine. Assuming such an extreme, however, we find the resistance per horsepower, when reduced as shown, permits an increase in speed from 232 to 241 m.p.h. or only 9 m.p.h. On the other hand, we can take this same engine and assume that, keeping its weight the same, we modify its structure so as to halve the head resistance of the engine itself, due to its shape. This change, which is entirely within the realm of possibility, would increase the speed to 290 m.p.h., and would show that if we could get a 420-hp. engine with a cross-sectional area permitting a good shape that would not be much over 2 ft. high and 9 in. wide, we could approach a speed of 300 m.p.h. Evidently, therefore, even admitting that some of the assumptions made necessary to derive this simple chart are apt to vary, we nevertheless find a lesson of the greatest importance which promises much in the future of aviation. This shows how much more important the head resistance of an engine is than its weight. Let us urge the builders, therefore, to abandon their unwarranted race for lighter weight per horsepower, bringing with it tremendous expense in construction, a lack of reliability and innumerable difficulties in service, and that they begin on a new line offering far greater possibilities by making the shape and disposition of their engines more suitable to airplanes, with low head-resistance considered as a fundamental. An engine of sufficiently well-studied shape will permit greater weight, more reliability, and less construction expense. This will improve the practicability of airplanes to an enormous degree, and with it bring improved performance.

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DESIGN FACTORS FOR AIRPLANE RADIATORS

By Samuel R Parsons[1]

The paper defines properties that describe the performance of a radiator; states the effects on these properties of external conditions such as flying speed, atmospheric conditions and position of the radiator on the airplane; enumerates the effects of various features of design of the radiator core; and compares methods that have been proposed for controlling the cooling capacity at altitudes. Empirical equations and constants are given, wherever warranted by the information available.

This paper presents in brief form the more important results of the investigation of airplane radiators at the Bureau of Standards. Approximate empirical equations and constants are given wherever possible, but all discussion of experimental methods is omitted. The work is treated in detail, with descriptions of the experimental methods and mathematical treatment, in a series of reports, written by various members of the staff, published by the National Advisory Committee for Aeronautics.

The fundamental requirement for a radiator for an airplane engine is that it shall maintain the temperature of the water in the cylinder jackets within a limited range. In so doing it must dissipate heat under conditions that vary between wide limits. The speed of the airplane and consequently the rate at which air passes through the radiator are much greater for level flight at full throttle than for maximum rate of climb. Atmospheric temperatures vary widely between summer and winter, and between the ground and great altitudes; also, the density of the air falls off rapidly with altitude, being about one-half as great at 20,000 ft. as at the ground. If a supercharging engine is used, the maximum speed of level flight may be considerably higher at great altitudes than near the ground.

With the use of supercharging engines, the most severe conditions for the radiator may occur at great altitudes. Since in general the most severe conditions for the radiator are those of climb at the maximum rate near the ground, the radiator is usually designed for this con-

[1] Bureau of Standards, Washington.

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dition and provided with some means for shuttering, to control its cooling capacity when under less severe conditions. But while a capacity for dissipating heat to the atmosphere is the primary requirement of the radiator, it becomes necessary in aeronautic work to give very careful consideration to the effects of the radiator on the airplane. First, it adds somewhat to the weight to be carried; second, it adds considerably to the air resistance of the airplane. That is, more power is required to drive the plane than would be needed if it could be operated without a radiator. The force required to push the radiator through the air, called its head resistance, is considerable at high speeds. For many of the types of radiator submitted for aeronautic use it is so great that if an airplane were driven at 120 m.p.h., a radiator large enough to cool the engine would absorb from 12 to 15 per cent of its power. The radiator causes absorption of power in two ways, in carrying its weight and in overcoming its head resistance. It also has other adverse effects on the plane, among which are (*a*) obstruction of the pilot's view, (*b*) modifications in internal construction of the fuselage to accommodate the mounting of the radiator, and (*c*), in military machines, liability to injury from hostile fire.

It is evident that while the best conditions for heat transfer require that the air shall flow rapidly past the cooling surfaces, this condition gives rise to high head resistance. The problem of radiator design thus becomes one of obtaining a maximum rate of heat transfer with a minimum absorption of power. The fundamental criterion for a good radiator is that it shall dissipate heat at the required rate with a minimum absorption of power. Various devices have been suggested, such as using the under side of the wing for the cooling surface or building the struts and other parts of the airplane with double walls and passing water through the spaces formed. While such construction might furnish heat transfer with no great increase in head resistance, it involves mechanical difficulties in construction and is essentially heavy, because, of the two walls that must contain the water streams, only one is available for effective cooling surface and, furthermore, to keep frictional resistance within reasonable limits, the water streams must be fairly thick on account of their great length. The construction would obviously be unsuitable for military use, because of its vulnerability. Such sur-

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face would probably be of about the same effectiveness as a dissipater of heat as an equal area of cooling surface made up into a good form of radiator.

The most important quantities that describe the performance of a radiator are given below. The units named are chosen for convenience and will be used throughout unless other units are specified. It will be noted that all quantities are reduced to unit frontal area of radiator core.

(1) Heat transfer is the rate at which heat is dissipated. It will be expressed in horsepower per square foot, or kilowatts per square meter, of frontal area

(2) Air flow is the mass flow of air through the core of the radiator. It will be expressed in pounds of air per second per square foot, or grams per second per square centimeter, of frontal area

(3) Head resistance is the force required to push the radiator through the air. It will be expressed in pounds per square foot, or kilograms per square meter, of frontal area. Head resistance of the radiator core is to be distinguished from head resistance "chargeable to the radiator," which includes any part of the resistance of the entire plane that may be due to modifications in design necessitated by the presence of the radiator. That is, head resistance chargeable to the radiator is the difference between the resistance of the entire plane and the resistance that it might have had if it could have been designed without a radiator

(4) Weight is expressed in pounds per square foot, or kilograms per square meter, of frontal area, including the water contained in the core

(5) The power absorbed is that used in overcoming head resistance and in lifting and sustaining the weight. It will be expressed in horsepower per square foot, or kilowatts per square meter, of frontal area. A distinction is to be made between the power absorbed by the radiator core and the power absorbed chargeable to the radiator, similar to that stated for head resistance

(6) The figure of merit is the ratio of the rate of dissipation of heat to the power absorbed, when both are expressed in the same units. A high figure of merit is the fundamental criterion for a good radiator

In considering the performance of the radiator, it is convenient to divide the possible positions in which it

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can be mounted on the plane into three classes (*a*) unobstructed, in which the flow of air through and around the radiator is unaffected by other parts of the plane; (*b*) obstructed, in which the flow of air through the radiator is reduced by the effects of other parts of the plane; and (*c*) slipstream positions, in which the blast from the propeller blows over the radiator. It will be noted that slipstream positions include both those that would be obstructed, except for the propeller, and those that would be unobstructed.

Heat Transfer

Heat transfer depends upon (*a*) the temperature difference between the air and the water; (*b*) the rate of flow of air through the air passages, and (*c*) the rate of flow of water through the water passages.

For the temperatures involved in the use of water-cooled radiators, heat transfer can be assumed to be proportional to the mean temperature difference between the air and the water. For practical purposes it can be regarded as proportional to the difference between the average of the temperatures of the water at entrance and exit and the temperature of the entering air. For a given temperature difference between air and water, the heat transfer increases with the rate of water flow, when the rate is low but, at the rates commonly used in aeronautic practice, heat transfer is not far from the maximum that can be obtained with change in water flow and can be regarded as practically independent of that rate. If for ordinary types of cellular radiators not more than 5 in. (13 cm.) deep in the direction of air flow, the water flow is above 2 gal. per min. per ft. width[2] of core per in. depth of core, or 1.63 cu. cm. per sec. per cm. width of core per cm. depth of core, the heat transfer can be regarded as independent of changes in the rate of water flow. In the following discussion it will be assumed that the rate of water flow is maintained high enough that its effects can be neglected.

For a given temperature difference and a rate of water flow sufficiently high to make the above assumption valid, the variation of heat transfer with air flow can be represented empirically by the equation

$$H = c\,T\,M^n, \text{ where}$$

[2] A dimension perpendicular to the general directions of both water flow and air flow.

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H = the heat transfer
T = the difference between mean water temperature and the temperature of the entering air
M = the mass flow of air
c = a constant
n = a constant

For the English units, if T is taken as 100 deg. fahr., c ranges from 6.4 to 15.0 for various types of core. For the metric units, if T is taken as 50 deg. cent., the range is from 80 to 200. The value of n ranges from 0.6 for types with large amounts of "fin" or indirect cooling surface, surface not backed by flowing water, to 0.9 or even unity for types with only direct cooling surface.

Air Flow

The air flow through the radiator, the mass flow, is ordinarily proportional to the speed of the airplane and to the density of the air. For unobstructed positions, positions such that the flow of air through and around the radiator is practically unaffected by other parts of the airplane, the mass flow of air can be computed from the equation

$$M = k \rho V, \text{ where}$$

M = the air flow in pounds per second per square foot of frontal area, or grams per second per square centimeter
V = the airplane speed in feet per second, or centimeters per second
ρ = the air density in pounds per cubic foot, or in grams per cubic centimeter
k = a constant for each type of radiator, but, since the constant k is dimensionless, any other consistent set of units might be used

The constant k is called the "mass-flow constant," and is equal to the fractional part of the air approaching the radiator that actually passes through it, or unity minus the fraction that is deflected around it. This mass-flow constant is a complicated function of the geometrical characteristics of the radiator, but for the more usual types with cellular construction it ranges between 0.60 and 0.85. For radiators of the "fin-and-tube" type, the mass-flow constant may be much less, and certain peculiar types that produce a whistling sound when in an air stream have no mass-flow constant, because the air flow is not proportional to the airplane speed. Both of these types, however, are unsuitable for general aeronautic use, because of excessive head resistance.

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When the radiator is in an obstructed position, as in the nose of the fuselage or the wing, the air flow through the core is in general much less than it would be if the radiator were unobstructed. Because of the devious path that must be followed by air that enters the fuselage through a nose radiator, a large portion of the air will be brought up to a speed approaching that of the airplane before finding its way out from the fuselage. This acquisition of speed is accompanied by a considerable absorption of power, and builds up a considerable air pressure in front of the radiator. Furthermore, air escaping from the sides of the fuselage interferes seriously with the flow of air past the sides, which might otherwise be fairly well streamlined. These considerations show that a radiator in the nose of the fuselage can be expected to increase greatly the resistance of the fuselage, and to give only a small flow of air through the radiator. For positions in the nose of the fuselage the mass-flow constant probably ranges between 0.3 and 0.7, depending upon the type of core and the provision made for letting the air out of the fuselage after it has entered through the radiator.

In considering a radiator mounted in the wing it should be borne in mind that, with wings of the present types, the air flow cannot be large, for, while the wing is designed to cause a difference in pressure between the upper and lower surfaces, it is not designed to maintain such a pressure difference when air is flowing from one surface to the other. The region of low pressure on the upper side of the wing occurs only near the surface, and even a small amount of air flowing up through the wing, in the case of a wing radiator, will bring the pressure in this region nearly up to that on the under side of the wing, so that only a very small air flow can be maintained. For a radiator mounted in the wing, the mass-flow constant is probably between 0.05 and 0.25.

When the radiator is either wholly or partly in the slipstream of the propeller, the air flow and consequently the heat transfer are somewhat greater than they would otherwise be for the same position. The effect of the slipstream evidently varies with different positions and with different types of airplane, but it is usually assumed that the speed of the air stream relative to the radiator is 20 to 25 per cent greater in the slipstream than outside of it. The relative increase in air flow through the

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radiator is probably somewhat less than the relative increase in speed past the radiator, because in the slipstream the air does not strike the radiator in a direction normal to its face.

Head Resistance

The head resistance of the radiator can be assumed, for usual purposes, proportional to the square of the flying speed and to the density of the air. For unobstructed positions it may be represented by the equation

$$R = b \rho V^2, \text{ where}$$

R = the head resistance in pounds per square foot, or kilograms per square meter, of frontal area
V = the airplane speed in miles per hour, or in meters per second
ρ = the air density in pounds per cubic foot, or grams per cubic centimeter
b = a constant for each type of radiator

The value of b ranges between very wide limits. If the English units are used, for cellular radiators with straight-sided air tubes, it ranges from 0.0009 for cores with very large free area to 0.0023 for types with very small free area; for fin-and-tube radiators, unless very open, it exceeds 0.0020; and for irregular types with turbulence vanes it may run as high as 0.0026. The corresponding values for the metric units are respectively 1.4, 3.5, 3.1 and 4.0.

When the radiator is placed in the nose of the fuselage, the head resistance chargeable to the radiator, meaning the difference between the head resistance of the complete airplane and the resistance that it might have had if it could have been designed without a radiator, is in general very large and, for a given flying speed, the head resistance chargeable to the radiator increases with increase in air flow. It is considerably greater for a radiator placed in the nose of the fuselage than when the nose of the fuselage is streamlined and a radiator of equivalent cooling capacity is placed in an unobstructed position. A radiator placed in the wing increases, in general, the resistance, or drag, of the wing, but the increase is not large and there may even be a decrease at certain angles of attack. The radiator, unless shuttered, will inevitably decrease the lifting power of the wing.

If the radiator is placed in the slipstream, the head resistance chargeable to it is probably approximately

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equal to what it would be if the propeller could be removed and the airplane driven by some other means at such a speed as would give the same speed of air relative to the radiator. If this is true, the assumption that the speed of the slipstream relative to the radiator is from 20 to 25 per cent greater than the flying speed would apply to head resistance as well as it does to air flow. Since head resistance varies as the square of the speed, an increase of 20 per cent in speed results in an increase of 44 per cent in resistance. The effect of the swirl of the slipstream is similar to that of yawing the radiator, which is to increase the head resistance for unobstructed positions and for positions that would be unobstructed but for the propeller. For positions that would be obstructed without the propeller, as in the nose of the fuselage, the effect of the swirl of the slipstream is to make the air flow somewhat less than it would be if there were no swirl and, since for such positions the head resistance chargeable to the radiator increases with increased air flow, the effect of the swirl probably compensates to a slight extent for the effect of the increased speed of air due to the propeller.

Power Absorbed

Since in this paper the power absorbed is reduced to unit frontal area, the statements apply to the power absorbed by a given radiator, rather than to the power absorbed in cooling a given engine. The power absorbed is composed of two parts: that due to head resistance and that due to weight. Since the head resistance varies approximately as the square of the flying speed, and the power can be measured by the product of a force and a velocity, the power absorbed due to head resistance varies approximately as the cube of the speed. Since, however, the weight is sustained by a "lift" on the wings, which is a constant and equal to the weight, and since this is accompanied by a "drag" that is proportional to the lift for a given angle of attack, the power absorbed due to weight is more nearly proportional to the first power of the speed, and is dependent upon the lift/drag ratio of the airplane. The power absorbed can be computed from the equation

$$P = k\left(R + \frac{w}{r}\right)V, \text{ where}$$

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P = the power absorbed in horsepower per square foot, or kilowatts per square meter, of frontal area
R = the head resistance in pounds per square foot, or kilograms per square meter, of frontal area
w = the weight of the core and the contained water in pounds per square foot, or kilograms per square meter, of frontal area
r = the lift/drag ratio of the airplane
V = the flying speed in miles per hour, or meters per second
k = a conversion factor which is 0.00267 for the English units and 0.00980 for the metric units

For speeds below 60 m.p.h., or 30 meters per sec., the weight is of considerable importance in comparison with the head resistance, but as the speed increases it becomes relatively less important and for speeds as high as 100 m.p.h., or 45 meters per sec., the difference in weight between one radiator and another is of but small importance.

The figure of merit, being the ratio of heat transfer to the power absorbed, is dependent upon all the factors that influence those quantities. It decreases with increase of speed, falling off very rapidly at the lower speeds and but slowly at the high speeds. It is given by the equation

$$F = \frac{H}{P}, \text{ where}$$

F = the figure of merit
H = the heat transfer and
P = the power absorbed, both measured in the same units

Special Features of Core Design

For unobstructed positions the total heat transfer, air flow, head resistance and power absorbed can be taken as proportional to the frontal area of the core, with small corrections to the head resistance and the power absorbed values on account of headers and connections. The figure of merit is of course independent of size, except as affected by these corrections. When the radiator is in an obstructed position, no simple statement can be made in regard to the effect of its size, because the influence of the surrounding parts of the structure may be very great. This is discussed later under the heading Effects of Position on the Airplane.

Increasing the depth, the dimension parallel to the direction of the air flow of a particular type of radiator increases its heat transfer for a given air flow by increasing the amount of cooling surface, but the added

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surface becomes less and less effective as the depth is increased, on account of the rise in temperature of the air in its passage through the radiator and the consequent decrease in temperature difference between the air and the water. Furthermore, the resistance to air flow increases with the depth, so that the air flow falls off for a given flying speed. An increase in depth is accompanied by an increase in head resistance, weight and power absorbed, but at the smaller depths the disadvantage of the increased absorption of power is less than the advantage of the increased heat transfer, and the figure of merit rises to a maximum at a certain depth which varies with different airplane speeds.

Estimates based on empirical equations indicate that the most efficient depths for certain general types of radiators are given in Table 1.

TABLE I—MOST EFFICIENT RADIATOR DEPTHS FOR UNOBSTRUCTED POSITIONS

Type of Radiator	Airplane Speed, m. p. h.	Depth, in.
¼-in. square cell	60	5
	100	8 to 10
	130	9 to 13
Flat plate, plates about $\frac{1}{16}$ in. thick ½-in. pitch[a]	60	8
	90	10 to 12
	120	12 to 15
¼-in. pitch[a]	60	6
	90	7
	120	7 to 9

[a] Measured across the face of the radiator, from center to center of the plates.

The change in the figure of merit with any change in the depth is much less rapid at high than at low speeds and, if considerations of construction make a small frontal area very desirable, the depth can be considerably increased over the optimum value, for use at the higher speeds, without greatly reducing the efficiency.

The free area is the fractional part of the frontal area of the core that is open for the passage of air. For use in unobstructed positions a large free area is desirable to increase the air flow and decrease the head resistance, and should be sacrificed only for the sake of compactness of the radiator. Care taken in making the

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water tubes as narrow as is compatible with sufficient strength and space for water flow is repaid by an increased radiator efficiency.

For use in unobstructed positions, it is important that the air passages should be straight and as smooth as is practicable, to facilitate the air flow and reduce the head resistance. Projections, indentations and holes in the sides of the air tubes add greatly to the head resistance without causing a corresponding increase in heat transfer. The slight advantage of saving in metal gained by punching holes in the indirect cooling surfaces is more than outweighed by an increased head resistance and an increase in the turbulence of the air, which, although it might be thought to increase the heat transfer, causes such a reduction in the air flow that the heat transfer for a given flying speed may be actually reduced.

In general, all surfaces past which air flows should be continuous from the front to the rear of the radiator, to give a maximum of effective cooling surface with a minimum air resistance. It is important for the designer to bear in mind that skin friction between air and the surfaces past which it flows is only a part of the head resistance, and that the losses at the entrance and the exit of the air tubes are very great, amounting sometimes to as much as one-half of the total head resistance. Smoothness of cooling surfaces is desirable and reasonable cleanness of surface is essential. A highly-polished surface has been shown to dissipate 15 per cent more heat for given conditions of air flow and temperature than an ordinarily smooth surface; and a surface lightly smoked has been shown to dissipate 10 per cent less heat than a surface only ordinarily smooth but clean. Corresponding but less noticeable effects have been observed on air flow and head resistance, and it is clearly shown that the efficiency of a radiator can be increased by polishing the cooling surfaces; but if the surfaces are kept reasonably clean, the differences in smoothness between surfaces usually encountered in actual practice are not great enough to show any very marked difference in radiator performance.

Measurements of temperature and pressure in the air tubes of a radiator indicate that the air flow is turbulent, at the speeds encountered in practice, for the entire length of the tubes. If a radiator of cellular type is to be used in unobstructed positions, the addition of spiral vanes or other devices which might be thought to increase tur-

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bulence is detrimental to the efficiency of the radiator. Such devices may appear to give an increased heat transfer for a given air flow because of the increase in the amount of cooling surface, but in tests of a large number of widely differing types of radiator there has been very little indication that the heat transfer per unit cooling surface is increased, and in some cases it is decreased. If a comparison is made at a definite flying speed, the addition of turbulence devices greatly reduces the air flow, and any tendency toward an increase in heat transfer per unit frontal area is often, if not always, overbalanced by the effect of the reduced air flow. Turbulence devices greatly increase head resistance.

The indirect cooling surface is the cooling surface not backed by flowing water. Indirect surfaces, or "fins," can be used to good advantage if proper attention is given to thermal conductivity, thermal contact between the indirect surface and the water-tube walls and shortness of the distances that heat must be conducted through the fins. The use of indirect cooling surface amounts to closing a water tube by pressing the walls close together, or to substituting a single sheet of metal for a water tube. The advantages are in saving the weight of water contained in the tube and, in the latter case, the weight of one wall, while allowing relatively large free area of core for a given area of cooling surface. The disadvantage arises from the fact that heat must be transferred by metallic conduction for a distance along the fins and away from the water-tube walls, before being dissipated from the surface to the air. Since heat can be conducted along the fins only with a drop in temperature, the temperature difference between metal and air is less for fins than for direct surface and decreases with distance from the sources of heat. Not only is thermal conductivity important in the fins, but thermal contact between the fins and the water-tube walls is very important, although in many types of radiator it appears to have received but little attention. Indirect surfaces may touch the water-tube walls at a number of points and yet make very poor thermal contact. They should be soldered to the water-tube walls at every practical point, except where the metal of the fin is continuous with that of the wall.

If the efficiency of indirect cooling surface is defined as the ratio of its rate of heat transfer to that of an equal area of direct surface under the same conditions of temperature and air flow, then for the type of indirect

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surface commonly employed in square-cell radiators, where the fin is continuous with the water-tube wall on one side and its length in the direction parallel to the wall is large in comparison with its width in the direction perpendicular to the wall, the thickness of fin that will result in any given efficiency is directly proportional to the square of the width, to a power of the air flow that is approximately 0.8, and inversely proportional to the conductivity of the metal if formed by folding the metal over; the thickness of the fin includes both thicknesses of metal.

Table 2 shows the approximate thicknesses of fin that will give efficiencies of 90 and 95 per cent, with different widths. This table is computed for a fin long in the direction parallel to the tube wall, and narrow, of rectangular form, soldered or continuous with the walls on both edges. If only one edge is in good contact, the thickness must be multiplied by 4.

TABLE 2.—FIN THICKNESS FOR DIFFERENT WIDTHS, SPEEDS AND EFFICIENCIES

	Copper				Brass			
Efficiency, per cent	90		95		90		95	
Speed, m.p.h.	150	60	150	60	150	60	150	60
Width, in.								
0.250	0.0017	0.0008	0.0038	0.0018	0.0063	0.0030	0.013	0.0064
0.375	0.0039	0.0019	0.0085	0.0040	0.0140	0.0066	0.030	0.0140
0.500	0.0069	0.0033	0.0150	0.0073	0.0250	0.0120	0.053	0.0260
1.000	0.0280	0.0130	0.0610	0.0290	0.0990	0.0480	0.213	0.1030

If one-half of the cooling surface of a radiator is indirect, with an efficiency of 90 per cent, the total heat transfer of the radiator is only 5 per cent less than it would be if the efficiency of the indirect surface were 100 per cent.

The composition of the metal used for direct cooling surface backed by flowing water is unimportant from the standpoint of heat conduction, since almost any metal will conduct heat through the thin walls of the water tubes, with very little drop in temperature, as rapidly as it can be dissipated from the surface. The choice of metal should be based upon other considerations than thermal conductivity. For indirect cooling surface, however, the

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conductivity of the metal is important, as is shown in Table 2.

The special types of core include radiators made ot water tubes in the form of flat hollow plates placed edgewise to the air stream and with no indirect cooling surface. This type has been shown to be markedly superior in respect to heat dissipation per horsepower absorbed, over the ordinary types of cellular radiator for use in unobstructed positions on planes flying at the higher speeds. The mechanical weakness of the flat-plate type is an inherent disadvantage, but one that can doubtless be overcome. Radiators of the fin-and-tube type show very high head resistance and low air flow; for this reason they are unsuited for general aeronautic use.

Tests have been made on certain special types of core, made with water tubes deep in the direction of air flow, and narrow, placed side by side, one behind another, with spaces between consecutive rows in each direction. These types produce a shrill whistling sound when in an air stream of more than about 30 m.p.h., or 15 meters per sec., and show irregular properties. That is, the air flow through the core is not proportional to the flying speed and the head resistance is not proportional to the square of the speed. These types show very high heat transfer for a given air flow, but very low air flow for a given flying speed. They show also a very high head resistance, with the result that the heat transfer for a given flying speed is in general not high and the figure of merit is very low. The whistling types are not suitable for aeronautic use.

Effects of Position on the Airplane

The important effects of the location of the radiator on the airplane have already been stated on page 594. Such quantitative results as have been obtained to date are given there. Attention is called to the three classes of positions already defined. The unobstructed positions have the following advantages:

(1) Except for the effects of the slipstream, the air flow through the core, and consequently the heat transfer, are greater for unobstructed than for obstructed positions

(2) The head resistance chargeable to the radiator is considerably less for unobstructed positions than for positions in the nose of the fuselage, in the

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wing or inside of the fuselage. The effect of the slipstream is to increase the head resistance of a radiator that would otherwise be unobstructed

(3) Since air flow is greater in unobstructed than in obstructed positions and, therefore, heat transfer per unit frontal area is greater, it follows that the weight of a radiator may be less for a given cooling capacity when in an unobstructed than when in an obstructed position

(4) With reduction both in weight and in head resistance chargeable to the radiator, the power absorbed chargeable to the radiator is reduced by placing the radiator in an unobstructed position, rather than in an obstructed position

(5) With both increase in heat transfer and decrease in power absorbed, the figure of merit of an unobstructed radiator is considerably greater than that of the same type of radiator in an obstructed position

The location of the radiator in the nose of the fuselage is objectionable because of very large absorption of power for a given cooling capacity. Not only is the resistance of the airplane much greater with a nose radiator than with the nose properly streamlined and an unobstructed radiator of equivalent cooling capacity added, but the air flow through the core is so low that with engines of the higher powers it becomes necessary to enlarge the fuselage to accommodate a nose radiator of sufficient size to cool the engine.

The performance of a radiator in the wing has not been thoroughly investigated because of experimental difficulties, but enough data are available to show that the air flow, and consequently the heat transfer, are very low for a given flying speed, while the effect on the wing as such can only be detrimental.

The effect of the propeller slipstream is to increase to some extent the air flow and heat transfer of the radiator. No specific statement can yet be made in regard to its effect on the head resistance of radiators in obstructed positions.

The information at present available on the effects of different positions on the airplane points to the following statements regarding the types of core suitable for different positions:

(1) For unobstructed positions, the radiator should be characterized by straight smooth air passages and low head resistance

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(2) For positions in the nose of the fuselage, the head resistance chargeable to the radiator increases, for a given frontal area, with increase in air flow. The most suitable type of radiator will be one that gives a high rate of heat transfer with a low air flow. This consideration leads to the use of a compact type with a large amount of cooling surface per unit frontal area and, since the head resistance chargeable to the radiator does not increase with the head resistance of the core, cooling surface can be added, even in the form of spiral vanes or other turbulence devices, without serious detriment. Whether the turbulence devices really increase turbulence and thereby increase the heat transfer more than would be done by an equal amount of straight and smooth surface, is a question that needs further study

(3) For positions in the wing, the requirements are probably similar to those for positions in the nose of the fuselage

Flight Control of Cooling Capacity

Among the more important methods proposed for the control of the cooling capacity of the radiator in flight are the following:

(1) The use of detachable sections is good for seasonal corrections such as summer and winter conditions, and for change from one latitude to another

(2) The construction of retractable types that allow withdrawing the radiator or a portion of it into the fuselage when its full cooling capacity is not needed, is one of the best methods of control from the standpoint of heat transfer and head resistance. Only the portion of the radiator really required for use need be outside of the fuselage where it will affect the resistance of the plane. Difficulties may be encountered, however, in the design of the fuselage for such an installation of the radiator

(3) Some attempts have been made to use a radiator pivoted about a vertical axis, so that it can be swung into or out from the air stream. This method is unsatisfactory because when the radiator is turned about, or yawed, on a vertical axis, the heat transfer is increased for certain angles while the head resistance is also greatly increased. This method not only fails to give satisfactory control of cooling capacity, but adds greatly to the absorption of power

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(4) If the fuselage cannot be designed to accommodate a retractable radiator, the radiator can be divided into two parts and the two halves placed on opposite sides of the fuselage. This gives the advantage of an unobstructed position and allows control by shutters that may be two plates for each radiator, hinged at the side of the fuselage, to swing out and mask both the front and rear faces to any desired extent

(5) Shutters of the window-blind type are objectionable because they add greatly to the resistance of the radiator when closed, and their effect in increasing head resistance and decreasing air flow is by no means negligible when open

(6) Control by regulation of the water flow has been suggested, but no satisfactory method has been proposed. If the water is cut off from a part of the radiator, that part is likely to freeze at great altitudes or in cold weather; while a change in rate of flow is not practicable because, with rates commonly used in practice, the heat transfer is practically independent of the rate of flow

Altitude Effects on Performance

As an airplane rises to great altitudes, the decrease in density and temperature of the air has important effects upon the performance of the radiator. The reduction in temperature tends to increase the heat transfer in proportion to the increase in mean-temperature difference between the water in the radiator and the air through which it passes. The decrease in air density reduces the mass of air passing through the radiator for a given flying speed and thus tends to decrease the heat transfer by an amount corresponding, but not proportional, to the decrease in density.

Since the head resistance is practically proportional to the density of the air, the effect of the decrease in density is to reduce the head resistance for a given flying speed by an amount proportional to the decrease in density. The combined effect of density and temperature changes due to changes in altitude is to decrease the heat transfer for a given flying speed, but the head resistance also is decreased and for the higher speeds the figure of merit is in general somewhat increased. Estimates of probable densities and temperatures at altitude can be made from meteorological data, and the performance of a given radiator at altitude can be estimated from its perform-

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ance at ground level by the use of the equations already given for air flow, heat transfer, head resistance, power absorbed and figure of merit.

Regarding the effects of engine and plane performance on radiator performance, the equation already given can also be used, with the aid of meteorological data, to estimate the performance of the radiator and the frontal area required, under varying conditions such as the maximum rate of climb or level flight at all altitudes, if enough is known about the performance of the engine and of the airplane to determine the flying speed, the rate at which heat must be dissipated and the lift/drag ratio of the airplane, under the different conditions.

FLYING AN AIRPLANE ENGINE ON THE GROUND

By S W Sparrow[1]

The very complete laboratory tests of airplane engines at ground level were of little aid in predicting performance with the reduced air pressures and temperatures met in flight. On the other hand, it was well-nigh impossible in a flight test to carry sufficient apparatus to measure the engine performance with anything like the desired completeness. The need clearly was to bring altitude conditions to the laboratory where adequate experimental apparatus was available and, to make this possible, the altitude chamber of the dynamometer laboratory at the Bureau of Standards was constructed. The two general classes of engine testing are to determine how good an engine is and how it can be improved, the latter including research and development work.

Recent standard comparative tests between an Hispano-Suiza and a Liberty engine were made to provide a reasonably satisfactory basis for predicting an engine's value for a given service and such runs were selected as seemed most properly to belong to a program of this kind. Four general classes of these runs are specified and the test results are given in a series of curve charts which are explained. Altitude and propeller-load results are presented in charts and discussed and the omission of temperature runs is justi-

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fied to a certain degree. The decrease in engine power at great altitudes is considered and, in conclusion, the value of carrying out such a program of tests upon a large number of engines is emphasized. Knowing that one engine is better than some other, the difference between them furnishes a suggestion at least as to where to search for points of superiority.

In the early part of the war there was much dissatisfaction with the existing methods of testing airplane engines. The very complete laboratory tests made at ground level were of little aid in predicting performance with the reduced air pressures and temperatures met in flight. On the other hand, it was well-nigh impossible

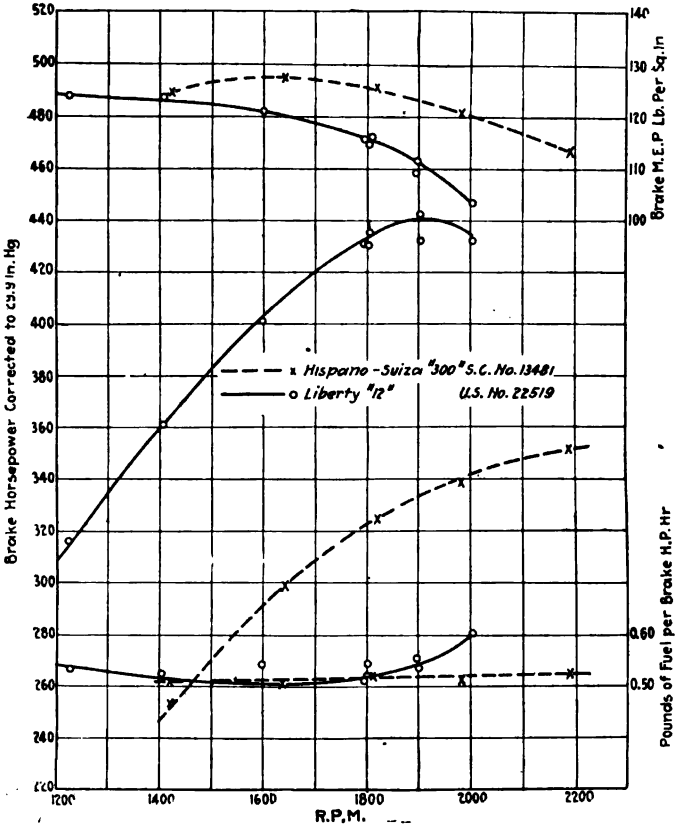

FIG. 1

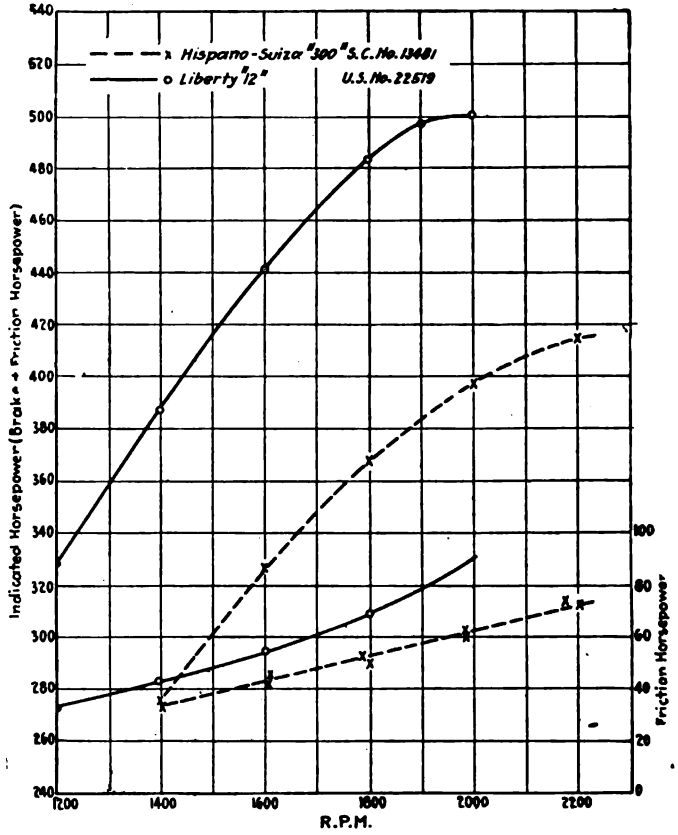

FIG. 2

in a flight test to carry sufficient apparatus to measure the engine performance with anything like the desired completeness. The need was clear; it was to bring altitude conditions to the laboratory where adequate experimental apparatus was available; in other words, to fly the engine on the ground. To make this possible, the altitude chamber of the dynamometer laboratory at the Bureau of Standards was constructed.

The work here naturally divides into two general classes. The first aims to determine how good the engine is; the second, how it can be made better. The latter class includes research and development work; from its nature, any program for such work must be flexible.

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This by no means implies the absence of a definite plan of procedure but rather recognizes that the completion of one step is necessary to determine the line to be followed in subsequent investigations. Moreover, this class of work should respond quickly to each need of the industry or, better yet, it should anticipate these needs. Work of the first class, on the contrary, is essentially dependent upon a program that is fairly well fixed. It is strictly work of measurement, comparing the perform-

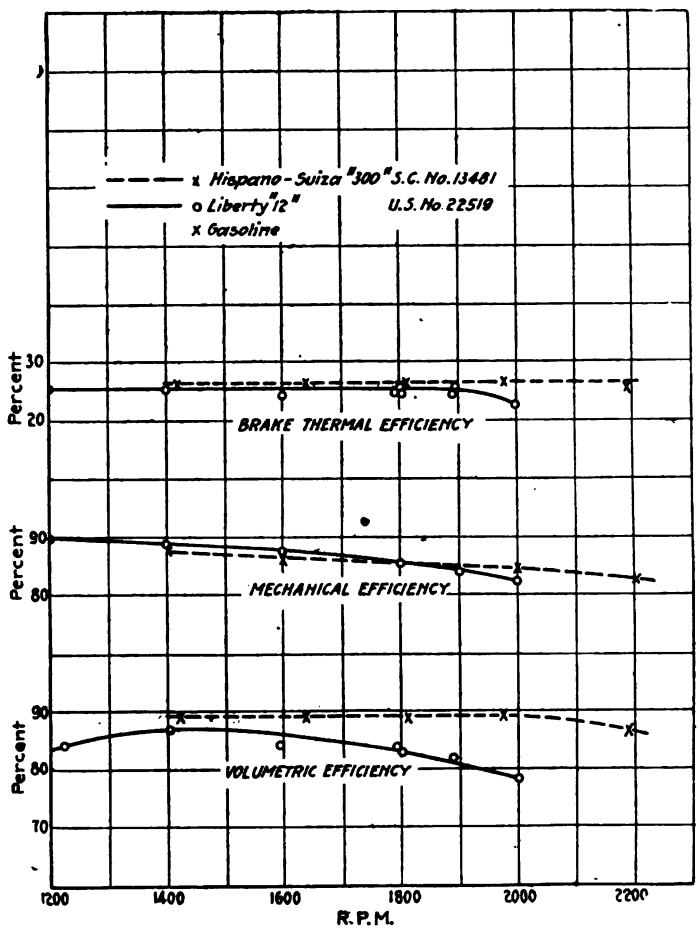

FIG 3

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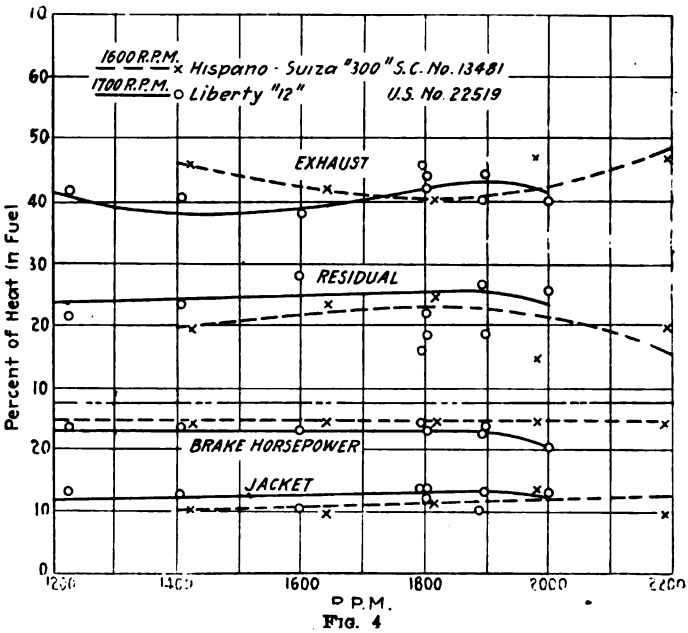

FIG. 4

ance of one engine with that of another, or with some predetermined standard. This requires decisions as to what measurements are most necessary, what standards are most suitable. Nor should it be forgotten that a Government laboratory should serve the industry of the whole nation, and that the value of any program of tests lies in the degree in which it furnishes the information that the industry requires. It is to call attention to some of these requirements that this paper is presented.

STANDARD COMPARATIVE ENGINE TESTS

Obviously, comparative tests of engines may be as diverse in nature as are the questions such tests seek to answer. It should be possible, however, to outline a standard program which will provide a reasonably satisfactory basis for predicting the engine's value for a given service, and yet not consume so much actual running time as to prohibit tests upon the same engine in that service. From recent experiments made at the Bureau with a Hispano-Suiza and a Liberty engine, there have been selected those runs which seem most properly to belong to such a program.

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These include

(1) Full-power runs at ground altitude over speeds ranging from 1200 to 2200 r.p.m.

(2) Full-power runs at two speeds and at altitudes ranging from ground level to 25,000 ft.

(3) Propeller-load runs in which the dynamometer was adjusted so as to produce approximately the same load as would be imposed by a propeller at speeds ranging from about the half-load speed to that of full load. These were made at altitudes of 5000, 10,000 and 15,000 ft.

(4) Friction-horsepower runs in which the engine was driven by the dynamometer. These were made over the same speed range as the first series and at ground level and an altitude of 15,000 ft.

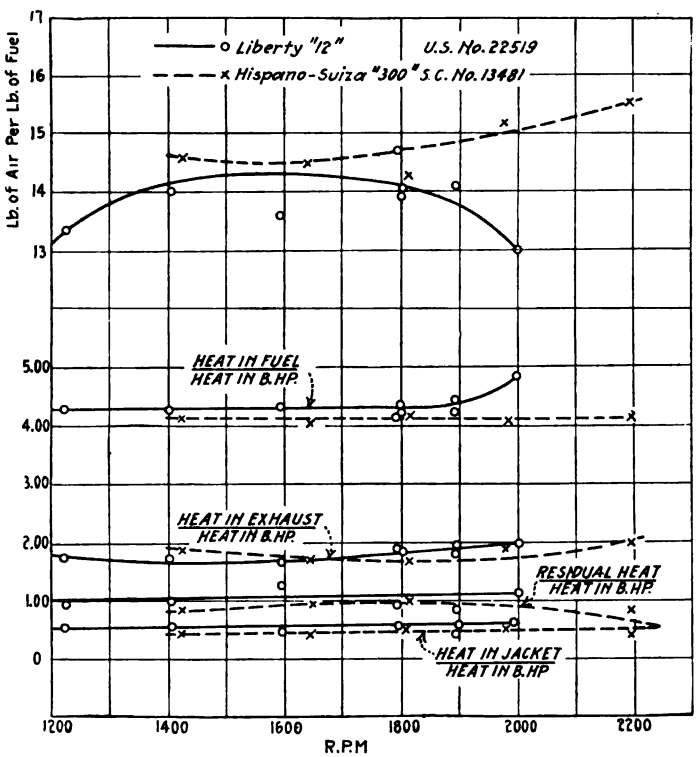

FIG. 5

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To the engineer, appreciative of the value of essentially reproducing service conditions in test work, the first series of observations may appear ill advised in that it subjects the engine to conditions unlikely to be met in practice. Justification for the full-power ground runs lies in the ease with which they can be duplicated with the equipment available at most laboratories and flying fields. This test then serves in a measure as representative of the series so long as an engine can repeat its previous performance on the ground it is likely to repeat its previous performance at altitude. The altitude power runs are perhaps the most important of all, inasmuch as

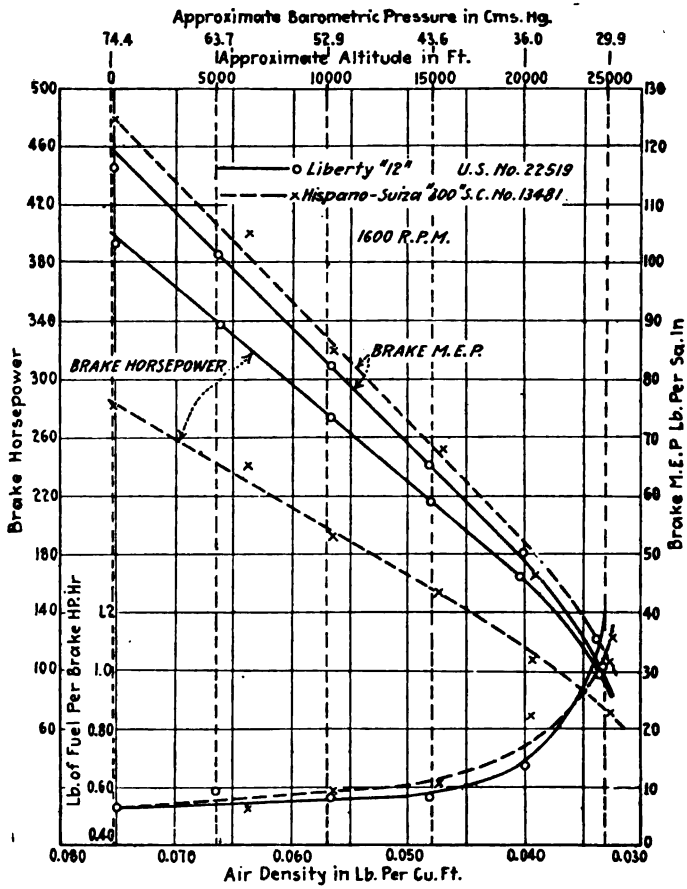

FIG. 6

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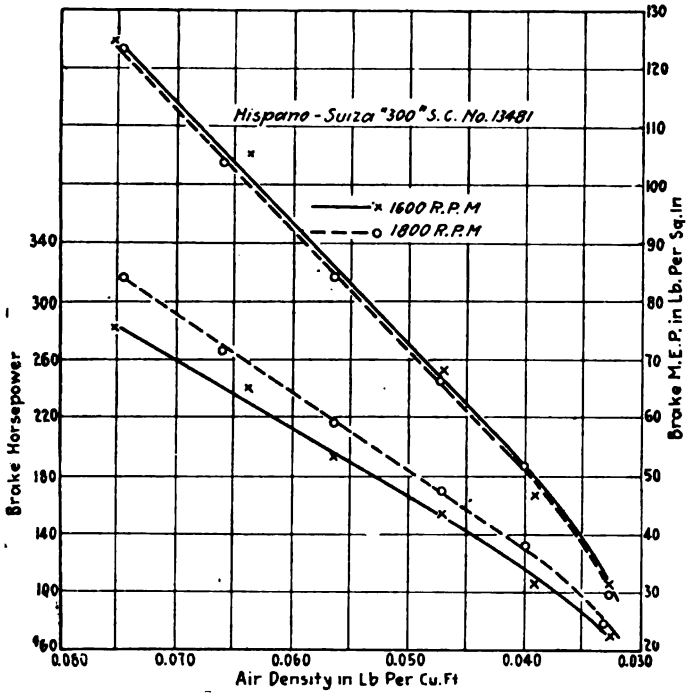

FIG. 7

they show directly the effect of changes in altitude upon the full-load performance of the engine. The propeller load shows primarily the influence of carbureter and inlet-manifold characteristics upon fuel consumption, while the friction runs give information necessary in the determination of mechanical efficiency. Some of the most important results of these tests are presented graphically in the accompanying figures. Since results and not methods are of vital importance, it is by the study of these results that the value of the foregoing series of tests can best be gaged.

CURVES OF TEST RESULTS

Figs. 1 to 4 are based upon the ground runs. Their purpose is clear. Expressing it, in its simplest form, the brake-horsepower curve tells what the engine can do, and the fuel consumption curve tells the price it exacts for doing it, while the brake mean-effective-pressure curve furnishes a measure of performance from which the size

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of the engine has been eliminated. Friction-horsepower measurements show the power expended in overcoming internal friction and pumping losses. Adding these to the brake horsepower gives the quantity termed indicated horsepower, the approximate power developed in the engine cylinders. This measurement often explains the superiority of one engine over another, although it is always by the brake-horsepower measurement that such superiority is first determined. In Fig. 3 the usual efficiencies are given, namely thermal, expressing the degree to which the heat energy in the fuel is converted into brake

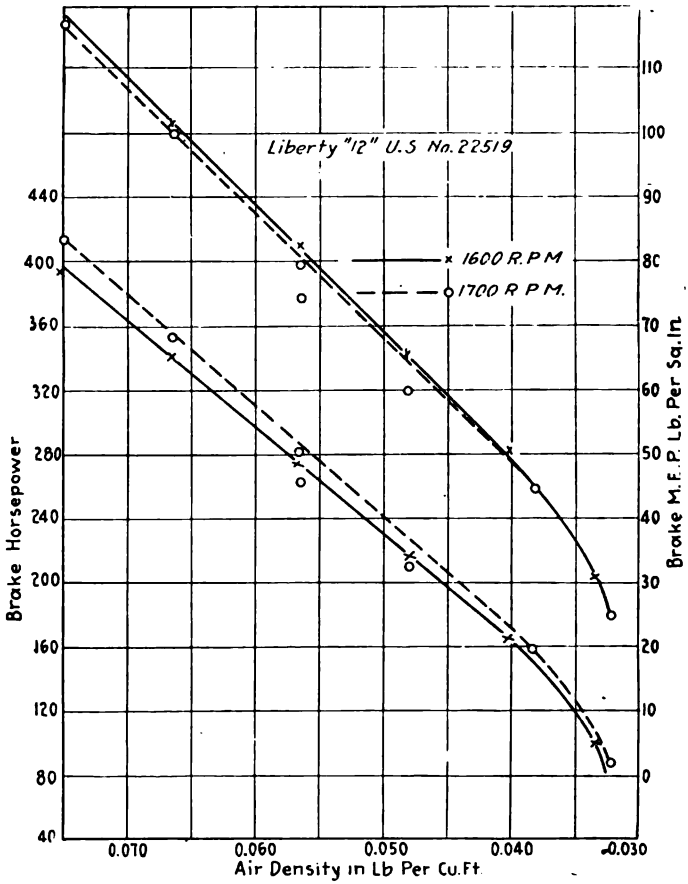

FIG. 8

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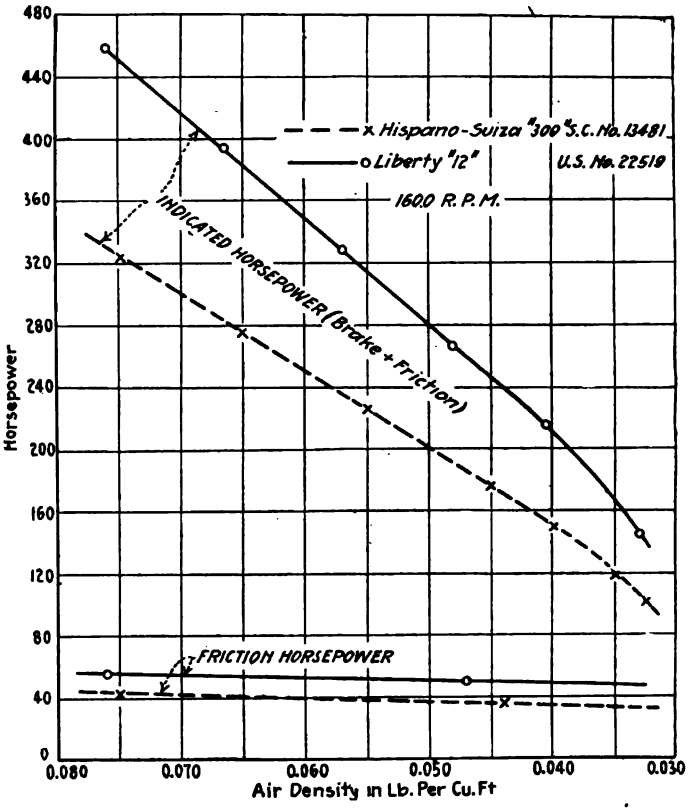

FIG. 9

horsepower; mechanical, giving the degree with which the power developed in the cylinder appears as brake horsepower, and volumetric, the pumping efficiency of the engine in drawing in its charge. A complete report of a test of this sort would include many curves omitted here, since they serve primarily as intermediate steps in locating others. Thus, plots of pounds of fuel per hour and pounds of air per hour aid in locating the air-fuel ratio curve shown on Fig. 4. Heat balances have been plotted with brake horsepower as a base, as well as with the conventional base, the heat in the fuel. To the designing engineer, the former method is of advantage in that it presents the heat distribution directly in terms of brake horsepower, a quantity which forms the starting point for much of his design work.

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The brake horsepower and brake mean-effective-pressure given in Fig. 1 have been converted to standard barometric pressure by multiplying the original values by the ratio of this pressure to the pressure at which the tests were made. To avoid making corrections for temperature, whenever possible this series of runs should be made at a predetermined temperature, 15 deg. cent. (59 deg. fahr.) for instance. In any event, a record of the temperature should be included in the report. Care should also be taken to maintain the oil and jacket-water

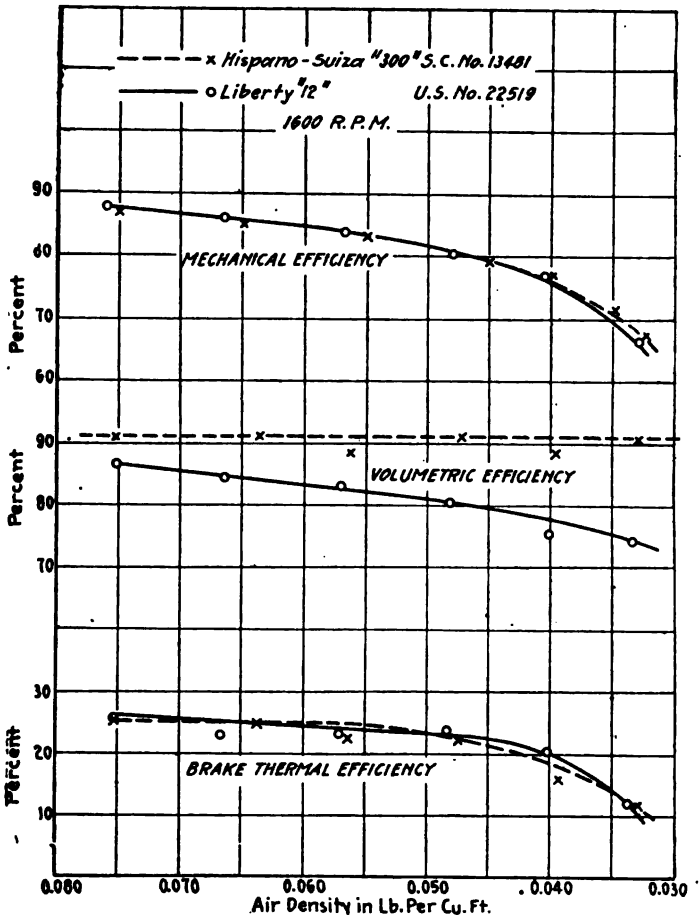

FIG. 10

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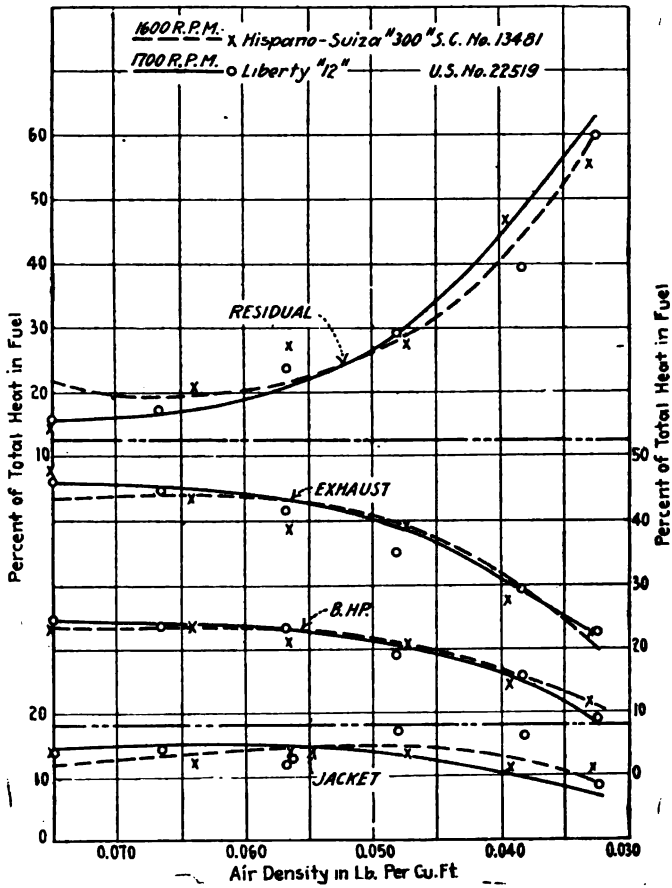

FIG. 11

temperatures as nearly as possible the same during friction as during the power runs. The importance of this and of recording these temperatures was made evident in a recent test where lowering the jacket-water temperature from 50 to 40 deg. cent. (122 to 104 deg. fahr.) increased the frictional losses 8 per cent with one grade of oil and 5 per cent with another.

OMISSION OF TEMPERATURE RUNS

Altitude and propeller-load results are given in Figs. 5 to 14. Figs. 7 and 8 are included merely to show how

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the observations at two speeds serve as checks upon each other and aid in locating the curves. There is considerable controversy as to whether results should be plotted against air pressure, air density, or altitude. Density seems most logical since, other conditions being equal; it is the weight of the charge that determines the power. Unfortunately, a change in temperature produces a change in power, whether density or pressure be held constant. This discussion is, however, of secondary importance, since it applies only to the expression of results

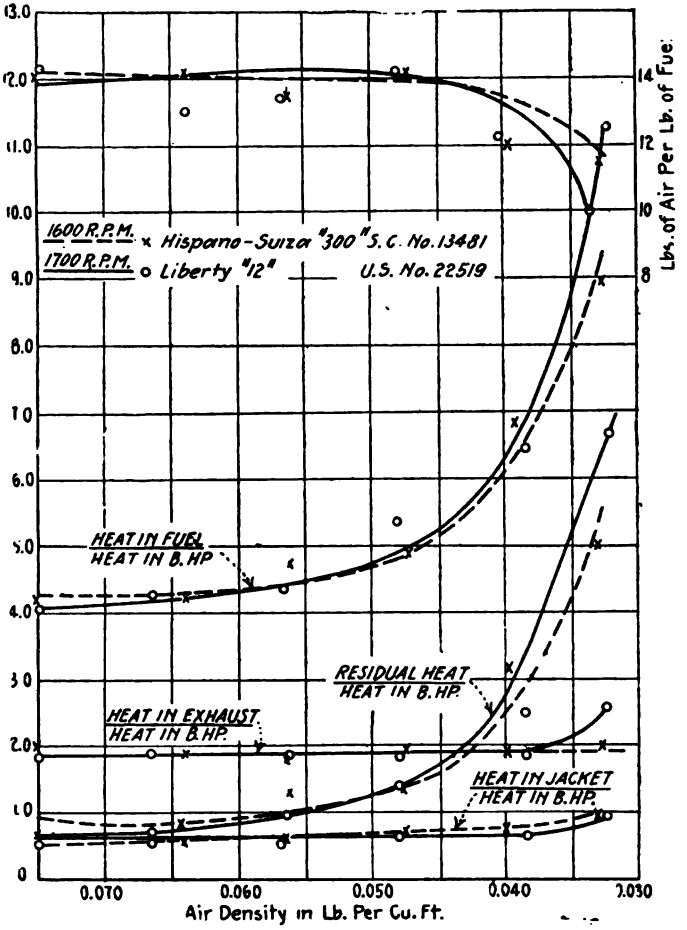

FIG. 12

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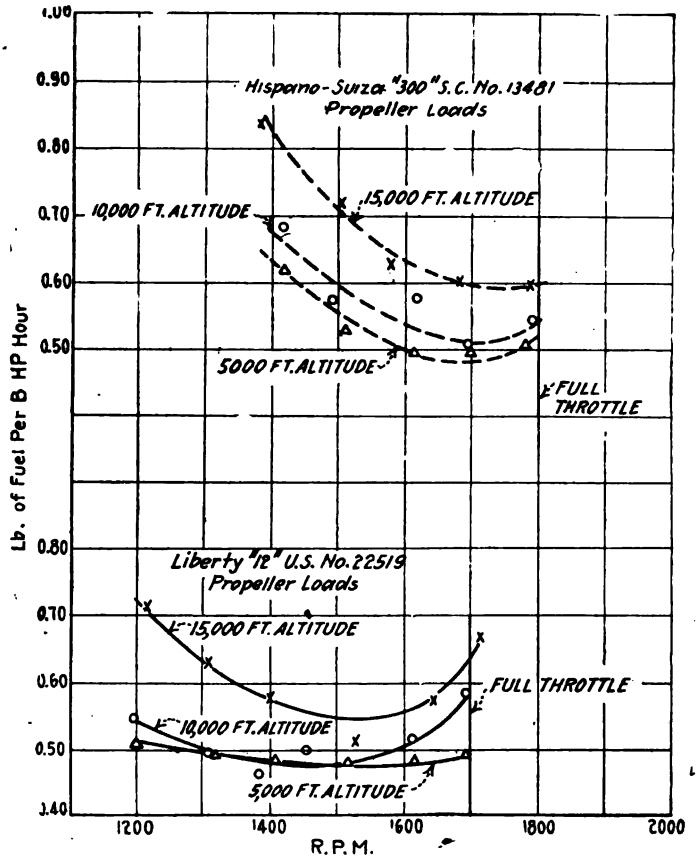

FIG. 13

and not to the conditions under which they are obtained. Much more pertinent is the query as to whether or not actual conditions shall be simulated to the extent of lowering the carbureter air temperature with each increase of altitude. Such a procedure was followed in these two tests, but it is questionable if this course is generally desirable. Any analysis of results is made difficult by the fact that the effects of changes in carbureter air temperature are superimposed upon those due to the changes in air density. Furthermore, the different temperature for each altitude makes changes from a pressure to a density base or vice versa decidedly cumbersome. If it be decided to maintain a constant carbureter air tem-

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perature, the next step is to select a temperature. Here again a considerable departure from actual conditions, namely, making the observations at a temperature somewhat above 0 deg. cent. (32 deg. fahr.), seems justified. Lower temperatures, through the resulting poor vaporization, freezing of carbureter air bleeds, etc., persistently cause erratic engine performance and uncertain comparisons. Rating an engine upon such performance seems hardly fair, since it is usually the carburetion that is at fault, and the exact nature of the fault is difficult to determine. On the other hand, it may be pointed out, with good reason, that it is decidedly advantageous to make the run at a low temperature in order that such troubles may be appreciated, even though the value of the engine comparison suffers in consequence. Perhaps the best solution for the present would be to make the runs at one speed at the high carbureter air temperature and the other speed at the low temperature, in both cases maintaining the temperature the same at all the altitudes. It is possible that this question will in time disappear through a generally followed tendency to preheat the carbureter air to a point above this troublesome range. I am of the belief that the gain in power from the use of air at extremely low temperatures scarcely ever compensates for the uncertain operation that usually ensues.

The foregoing remarks explain to a certain degree why temperature runs have been omitted. These are made for the purpose of finding how much a change in carbureter air temperature affects engine performance. This requires several carbureter settings at each temperature as, otherwise, slight changes in mixture ratio will produce differences in performance for which the temperature change is by no means responsible. When an engine is in production, one of the type should be subjected to such a test, but the running time required is so great as to prohibit its inclusion in the program under consideration.

Decrease in Power at Altitudes

It is of interest to note in Fig. 14 that in spite of the marked differences in construction between the Hispano-Suiza and the Liberty engines, the percentage decrease in both brake and indicated horsepower is the same for both engines at altitudes up to 20,000 ft. and an air density 0.040 lb. per cu. ft. Above this altitude the

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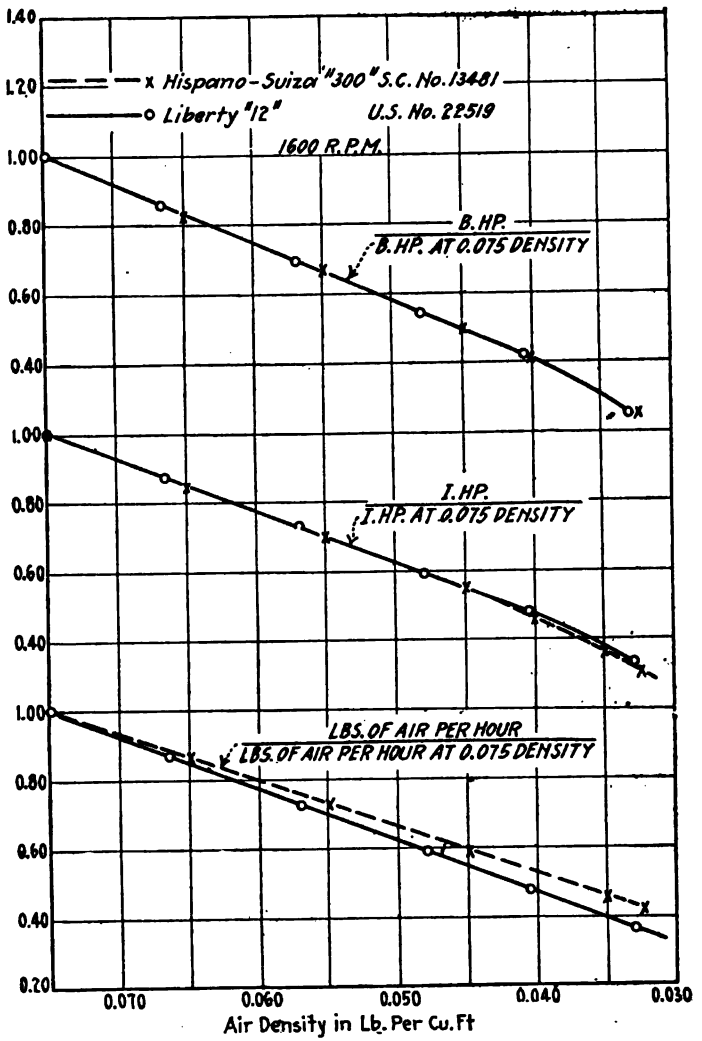

FIG. 14

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carbureter adjustment was inadequate, so that the curves are influenced by the over-rich mixture as well as by the density change. Carbureter characteristics, to a large extent, fix the form of the propeller-load curves of Fig. 13. Durability tests, analyses of weight distribution, inertia forces, bearing loads, etc., have been omitted, not from any failure to recognize their value but because such work is not dependent upon the equipment necessary for altitude tests. It can be done at any time and at almost any laboratory. That these tests did not constitute a serious drain upon the life of the engines is evident from the fact that the total running time of the Liberty engine was about 11 hr. and that of the Hispano-Suiza about 5 hr. This includes the "warming-up" time.

The value of carrying out such a program of tests upon a large number of engines can scarcely be overestimated. To the Government, accurate knowledge of the performance of such powerplants is especially valuable in the event of war. To the manufacturer, such tests always prove an incentive to better design. Nor is this work without its value to the research engineer. Knowing that one engine is better than another, the difference between the engines furnishes a suggestion at least as to where to search for points of superiority. Above all, it must not be forgotten that in laboratory tests engine failures seldom result in loss of life. Surely this will not be overlooked by an industry which has owed so much of its development to the fearlessness of its pilots.

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TRUCK AND TRACTOR MEETING

The Truck and Tractor Meeting of the Society held at the Hotel La Salle, Chicago, on Jan. 28, was a distinct success. The papers presented at the morning and afternoon sessions held closely the attention of the members, of whom there were more than 200 present.

The discussion was opened with a statement by A. H. Edgerton on the Use of Aluminum in Decreasing Unsprung Weight of Motor Trucks, particularly with reference to wheels. Following this Col. L. B. Moody of the Ordnance Department, presented a paper prepared by Past-president George W. Dunham on Artillery Motorization as Related to Caterpiller Traction. This paper elicited remarks by several members, the principal point of interest being the matter of the best policy for the Ordnance Department to follow in securing engines for installation in ordnance automotive equipment; that is, whether engines produced for commercial use should be used, or a line of engines of the various powers needed should be specially designed and standardized for the Government equipment in question. Prof. L. W. Chase of the University of Nebraska described in connection with his paper on Tractor Testing from the User's Standpoint the special testing plant and field which have been developed by a board of engineers under his supervision for making pulley and drawbar horsepower tests of tractors as provided for in Nebraska by law. The testing system that has been formulated includes the use of a towing dynamometer of the electric type.

During the afternoon session a valuable and comprehensive amount of information on the use of pneumatic tires on motor trucks of various capacities was given. S. V. Norton presented a paper entitled Relation of Solid and Pneumatic Tires to Motor Truck Efficiency, and C. M. McCreery treated the Design of Pneumatic-Tired Trucks. The technical sessions were concluded by the presentation and discussion of a paper by C. A. Norman and B. Stockfleth on a recent tractor engine test conducted by them. The authors each discussed features of the paper.

The dinner held in the evening, with over 600 present,

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was a happy occasion, music being provided by the Apollo Club. President J. G. Vincent introduced as toastmaster of the evening Fred Glover, who spoke directly to the point and amused the members greatly by relating briefly his experience in Washington in the Government service during the war. The members were honored by the presence of Major-General Leonard Wood, who gave a short, impressive address. E. J. Gittins, chairman of the tractor and threshing machinery division of the National Implement & Vehicle Association, discussed in an illuminating way the fundamental points involved in power farming.

Supplementing the remarks which had been made at the professional session in the morning by Col. C. L'H. Ruggles, chief of technical staff, Ordnance Department, Major-General C. C. Williams, chief of ordnance, stated in a very frank and straightforward way the great necessities of real military and industrial preparedness. He covered the essential points of the policy of different nations in this connection and endorsed highly the service of members of the Society and of its Committee in direct work and cooperative procedure with the Ordnance Department in connection with the development, design and production of ordnance automotive equipment.

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ADDRESSES AT THE TRUCK AND TRACTOR DINNER

The speakers at the dinner held in connection with the Truck and Tractor Meeting of the Society at Chicago on Jan. 28 included, in addition to Fred L. Glover who acted as toastmaster, Major-General Leonard A. Wood, U. S. A., commanding the Central Department; E. J. Gittins, of the National Implement and Vehicle Association, and Major-General C. C. Williams, U. S. A., chief or ordnance. The addresses which were enthusiastically received are given, substantially in full, on the following pages.

ADDRESS OF MAJOR-GENERAL LEONARD A WOOD

I have a very great appreciation of what the automotive engineering profession is doing. I remember very well being with the French and German armies when all Europe was on the verge of the great war which followed, and I was particularly struck with the want of any kind of motor transport. People were talking about it. We saw here and there some queer vehicles, but there was no motor transport to speak of. There were some traction trains, but they were hard to manage.

A year later we had what we called mass maneuvers. They were uncontrolled maneuvers covering some 300 or 400 miles. I borrowed twelve or fifteen motor trucks. This was looked upon as an experiment. But when we think what has happened in the past few years and what motor transport means today, we realize what the automotive engineers have done for transportation. I think none of us realizes what the automotive engineers will do for transportation. They are going ahead by leaps and bounds and there seems to be no limit to what they will do.

One thing must be done and that is to put over the good-roads program all through the country. We have been thinking and talking about a system of national highways. In some sections they are really under construction, but we ought to put all the influence we can be-

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hind the visions of those national highways which are so important, not only for the needs of peace but for the needs of possible war. Those hosts of lines of communication, those lines along our frontiers and the great connecting lines, when they are built and roads of proper construction are ready, our task will be larger than ever.

I hope the automotive engineers will continue their work in aviation; that is, on the engines for the various types of airplane. It seems to me that we are rather dropping back in that at a time when we ought to be going ahead and going ahead hard. We ought to keep up enough flying fields all over the country and try to push forward general training and development in aviation. No man can be an aviator long and we must always have additional aviators developing. We need the best possible type of engine. That type, I feel sure, the American automotive engineer will give us. I think we want to push that and keep it going.

I want to suggest and urge upon you that you do all you can to keep alive a reserve corps for the motor transport and a reserve corps in the various lines of the automotive engineering profession. Automotive engineers were simply invaluable to us in the great war and will be invaluable to us for the demands of peace. We want them to be ready to meet any possible emergency in the future. We must maintain the splendid motor-transport organization that was built up during the war; we have got to go ahead with it. We want to organize the automotive part of our national resources just as we organize any other. If we ever have any other great emergency, we should find a nation organized to a far greater strength than before as a result of the lessons of this war. The fighting line, the Army and Navy, might be compared to the edge of a heavy knife-blade. They are the cutting destructive force, but back of them is the great mass of steel which gives weight and rigidity to the edge, the organized resources of a nation, replacing the wastage of the edge and giving it weight to drive it home.

While that is true in war, it is also true in the pursuits of peace; in industry and the building up of commerce and trade. I think we have very severe competition ahead of us. The people in Europe have been tremendously knocked about; some of them, notably the Germans, are coming out very lean and light and ready for a keen commercial struggle. They have their financial dif-

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ficulties and all that, but it is well to remember that they have learned to live without export and import. They have acquired a practical thrift habit and their industries, their shops and their factories are undisturbed. Competition will come. We must build up, not only in the automotive but in every other line, the organization that we need to carry on our part in the big world program. We must build up an intense American spirit, absolutely American; not selfish, not narrow, but American. Back of it we must have a national conscience, which will make America quickly responsive to any situation which demands our assistance, but we want it to act always as America, and to remember that the mandate which we will always accept cheerfully is the mandate which comes from the conscience of the American people. That is our mandate. We have a strong mandate now, abroad. It is that we, with the money and wealth that have come to us in this war, do our full share in alleviating the conditions of distress and suffering on the other side. There is a big problem over there, and we have a big moral responsibility. I am not talking now of armed forces in Europe, or of intermingling with and intruding into European politics. I am speaking of responding to that one mandate which comes more and more to all of us as the days go on, and that is the mandate to put these suffering people on their feet, with food, shelter and clothing. It will be a big proposition, but the bread thus thrown on the waters will come back to us in many ways. We can do it without in any way intermingling with their affairs.

I wish we had the same progressive forces throughout the country as are represented by the Society of Automotive Engineers. I hope you will push forward the reserve idea for motor transport and do everything you can to standardize production. I also hope that you will put your best thought into the development of aviation, not necessarily for war, but for those commercial usages to which it will without doubt soon be devoted very largely.

ADDRESS OF E J GITTINS

I assure you that I deem it a privilege to be in this company. I will not presume to undertake to enlighten you on any of the technical questions of the industry, for I am not an engineer. Any discussion of agriculture must necessarily be based upon fundamentals. It is a fundamental business. It is the background, the

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foundation, of all human activity. Any people or nation that ignores this fact will not advance very far. The United States is primarily an agricultural country. The vast expanse of fertile land that we have is far in excess of the power that we have had available to till it properly. This has furnished the incentive for inventive development which has placed our country in a class by itself among all the nations of the world for producing crops with the minimum of human labor.

How we have advanced in this industry is illustrated in a paragraph of a little pamphlet issued by the Agricultural Publishers' Association, as follows:

> In 1885 the amount of human labor expended in growing an acre of corn was 183 hr.; today it is nineteen. In 1830 it required 66 hr. of human labor to grow an acre of oats; today it takes 6 hr. Sixty years ago the farmers cradled the wheat and hauled it by hand to the barn and then threshed it. For each bushel of wheat harvested, these operations required 183 min.; one man using the labor-saving machines now found on the farm can do the same work in 10 min. With a combined reaper and thresher, operated by steam or gasoline, and a gasoline tractor to plow and fit the land, less than 3 min. of human labor is required for producing a bushel of wheat.

While we have always had more land to till than we have had labor to till it properly, conditions have arisen in the last few years that have created an emergency, and reference to a few well-known facts will I think illustrate the truth of this statement. In the ten years prior to 1915 our immigration into this country was something more than 1,000,000 a year. In the last four years the immigration has been only about 200,000 and more people have been going out of the country than coming in. The population of the country in 1860 was about 31,000,000, of whom 5,000,000 lived in cities, less than 20 per cent. Even as late as 1880 80 per cent of our people lived on farms. Now the population is perhaps 105,000,000, with only about 30 per cent living upon farms. It is said that 8,000,000 people have moved from farms into the cities since 1900. Our increase in population since 1900 is more than 20 per cent, but our crop production has increased only about 10 per cent. I give these figures to call attention to the rapid change that has been going on in this country and leading up to the farm requirements of the present day. The effect of this great change in

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the relative city and country population is not only to curtail production of food products, but it is, in my opinion, one of the principal factors in the present high cost of living. That, in turn, is a principal factor in the present unrest throughout the world, an unrest that is even shaking the foundations of governments.

The progressive activities of American automotive engineers have met the situation in a remarkable degree, with the result that we now have hundreds of thousands of mechanical machines operating upon the farms as substitutes for human power. Perhaps the greatest and most arduous work of producing crops is the preparing of the soil for the seed. It is the tractor that has been developed to accomplish that work with the minimum of human labor. The tractor is not altogether a new departure, as some seem to think. Engines have been used on farms for fifty or sixty years, first as steam portable engines, then as steam traction engines. Steam traction engines were being used more and more for general farm purposes, but about the time they had been developed so that they were practical and being used generally, the internal-combustion engine was developed to a practical stage and applied in the place of steam power. Why did it take the place of steam power? Simply because it replaced more men. There is no piece of machinery anywhere, I believe, that is subjected to such continuous hard work and under such fearfully adverse conditions as farm machines, especially tractors that must work over the rough and dusty lands. I believe that most manufacturers do not fully appreciate this fact when first commencing to build their product, but it has been borne in upon them with the result that changes and improvements have been made continuously, until we now have practical machines. There are many things yet to be remedied. The industry is still in its infancy. Improvements are going on rapidly, although they are not so evident as formerly.

It seems to me that the question of shortage of human or mechanical power for the farm is so vital, so far-reaching, that it should enlist the attention and the assistance of even the Government. The evils, or the shortcomings, in the business have brought about regulatory legislation such as has been passed in Nebraska, and threaten to bring about more State legislation. This legislation should be welcomed, but it should be uniform in all States. That is the reason builders favor national

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rather than sectional regulation. The subject is of such importance, the question of production of crops is so far-reaching, that our national legislators should have personal interest in the question.

Farming is a hazardous business in many ways. There are many risks in it, more than in most other enterprises. The land must be tilled properly at the right season of the year. The crops must be taken off at the proper time and oftentimes very quickly to avoid serious losses. This means that the mechanical power which displaces the human power must be dependable to be available when required.

The one thought that I would like to leave with you is that we should strive, as engineers and manufacturers, to design and build so that farm power machinery will be dependable. We should also recognize the fact that most farm machinery is operated by inexperienced people. Hence it should be as near 100 per cent right as it is possible to build it.

ADDRESS OF MAJOR-GENERAL C C WILLIAMS

We are now passing into a new era, into a time when we must really make plans and crystallize the experience we have had during the past war, so as to make it available for the next war, because, if there is one sure thing ahead of us, a thing that is just as sure as death, it is that we are going to have another war.

We have now a general staff. It is organized for the purpose of studying world conditions, for making assumptions as to probable enemies and for working out plans of campaign both offensive and defensive. But when a plan of campaign, either offensive or defensive, has been made, only half of the work has been done. There is no use in raising an army of a million or several million men unless we can equip and sustain them in the field. If our experience in this war has taught us anything, it is that we should take the plans of campaign that are prepared by our general staff and turn them over to an industrial general staff, if you choose to call it so. This industrial staff can then develop the industrial plans that will be necessary in order that the industries of the country may be put in operation to produce with the least delay and the least friction, the material that is required to sustain the troops in the field.

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In a way, this is the thought that is back of the Army's relations with this Society. You have been extremely valuable to us during the war. We want to maintain the contacts that we have made with you. We want you to know what the Army problems are, what they will be during the next war, or any war that our general staff may make plans for. We want your assistance in working out our problems of development, design and production.

The war that has just closed left us, of course, with many more unsolved problems than there were in the beginning; that is, so far as munitions are concerned. Mechanical warfare experienced a tremendous development; but no one can say that the surface is very much more than scratched. We want to keep in touch with you concerning the developments that we foresee and to get your assistance in the developmental work, which is one of the most important things we have.

I had the good fortune to attend your 1919 Summer Meeting and there told you that we hoped to do certain things in the matter of getting in touch with you. Some of those things have been done with happy results. Your Society has appointed a committee of your ablest engineers to work with us, to go over our problems with us and to help us out in our work. That is already started and the cooperation between the Society and the Ordnance Department is all that we can desire. We look forward to maintaining it in the future. It will require effort on the part of all of us to do so because we cannot, in all probability, put out many orders. Congress probably will not give us much money. We hope that there will be some. We hope that we will have a chance to put a large proportion of our appropriations into the industries, because it is only by manufacturing the things that we want that you may learn how to manufacture.

The man who is commanding troops has a great advantage over us in preparing. He can get his regiments, brigades, divisions, army corps and armies and can inaugurate maneuvers in which he tries out his various theories as to how troops can be managed. I know of no way in which you can so maneuver in manufacturing a 16-in. gun. The only way is to build it.

Insofar as I am personally concerned, I am opposed to the complete manufacture of ordnance material in the arsenals. Unfortunately, there is a stronger and stronger

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indication in that direction. Many of our appropriations come to us requiring that the work shall be done in the arsenals. The very best way, the best solution of the ordnance material manufacturing problem, in my opinion, is the German solution, in which every agency of the Government was at the service of firms like Krupp and Ehrhardt, so that a munitions industry was built up. Young men coming out of the German technical schools and universities could go to Krupp and other places and find a career of honor and profit. A large force of trained men was built up, factories were built; in fact, the munitions industry was a going concern. The value to the Germans of organizations like Krupp, when the German nation was called upon to make its great effort, cannot be overestimated. Unfortunately, that method cannot be followed in the United States. The very best we can do is to manufacture at Government arsenals, with all the encouragement that we are permitted to give to private industries.

It is a great pleasure for me and for the officers of the Ordnance Department to work with you. We hope that in the years to come this good relation will be maintained. We are sure that it will be.

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TRACTOR TESTING FROM THE USER'S STANDPOINT

By Leon W Chase[1]

To test tractors for results valuable to the user, the reliability, durability, power, economy and utility should be determined. Standard tests measuring tractor utility and reliability are impossible practically and durability tests would be an extensive project, but tractor and engine-power tests and tests of the amount of fuel required for doing a unit of work can easily be made.

The University of Nebraska tests described were for belt and drawbar horsepower and miscellaneous testing for special cases. The four brake-horsepower tests adopted are stated. Tractor operating conditions are then reviewed. The drawbar horsepower tests include a 10-hr. test at the rated load of the tractor, with the governor set as in the first brake-horsepower test, and a series of short runs with the load increased for each until the engine is overloaded or the drive wheel slips excessively, to determine the maximum engine horsepower.

The special testing course devised and constructed is described and the plans for absorbing the power of the tractor stated. In this connection the Nebraska dynamometer car which was developed for work at the University is described and its operation explained.

Two general plans might be inaugurated in testing tractors; one has for its foundation the design of tractors, the other, their use. Testing tractors to obtain the information desired in their design necessitates testing for friction losses in the bearings, the gears and the entire transmission; for heat losses through the cylinder walls and the pistons, past the rings and through the exhaust gases and for information relative to valve openings, sizes, timings, stems, etc. An unlimited amount of testing can be done on tractor engines to aid the designer. To test tractors and obtain results that will be of value to the user, a test should be inaugurated that determines the reliability, the durability, the power, the economy and the utility of

[1] Professor of agricultural engineering, University of Nebraska, Lincoln, Neb.

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the tractor. It is practically impossible to devise tests which can be standardized and will measure tractor utility and reliability, and it would be a very extensive project to devise tests that would determine its durability. However, tests can very easily be made that will determine the power of a tractor and its engine and the amount of fuel required for doing a unit of work.

University of Nebraska Tests

In devising means for testing tractors in compliance with the State law requiring the University of Nebraska to test one model of each tractor sold in the State, the Board of Engineers has endeavored to devise a measuring unit that is standard for all tractors under all conditions, one that is exact and which eliminates the human equation. These have been divided into two general classes, belt horsepower and drawbar horsepower tests. In addition, there is a miscellaneous test, to be used only in special cases. In preparing the rules and the apparatus for making these tests, the board kept two principal points in mind. One was to devise apparatus and means for eliminating the human element; the other was to devise a standard means of testing each tractor which measured them all with the same unit. In other words, it endeavored to devise a kind of yardstick such that a tractor manufacturer could compare his machine with it so that if the tractor did not measure up to this standard he would believe that it was the fault of the tractor and not of the yardstick.

After considering that the manufacturer might desire to have his engine tested for the power it would deliver at the crankshaft, that it would be impossible to make such a test without removing the entire engine from the tractor because many machines have no means for connecting the crankshaft to any power-driven machine that could be made perfect and that many engines delivered their power to the belt through gears, it was decided that the most just and practical scheme for measuring the horsepower was to take the power delivered by the belt to the brake. This ruling of course complies with the Nebraska law, for it measures the power delivered by the engine to the machine the farmer contemplates driving.

After carefully considering the various types of prony, hydraulic and electric brakes, the last was decided upon

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because of its ease of manipulation, uniformity of operation and accuracy.

Four brake horsepower tests have been adopted for the Nebraska tests. They are, (*a*) a test at the rated load and speed for 2 hr.; (*b*) a test with load varying from a maximum to no load with all adjustments as in the previous test to show fuel consumption under varying loads and also speed control under similar conditions; (*c*) a test under the maximum load with the governor set as in the first test, but during which the carbureter can be adjusted to give its maximum power, and (*d*) a test at one-half load with the governor set as in the first test but with the carbureter adjusted for the most economical operation at this load.

Tractor Operating Conditions

Before describing the apparatus for making the drawbar horsepower tests, a discussion of the field conditions under which the tractor operates will be presented. To those who have not followed tractors while at work, it would seem an easy matter to test the machines when pulling plows. However, the conditions under which plows are used are so variable that no standard measuring unit could be devised; furthermore, it would not be practical to do such extensive field testing work. It does not seem possible to find two fields or, for that matter, a dozen furrows in a single field which will require the same draft and which will offer the same footing for a tractor. For instance, in some tests made by the University of Nebraska in one of the very level and apparently uniform fields of the State and with the same engine and the same plows set at the same depth, the draft was 4.54 lb. per sq. in. in one soil and in an adjoining soil 5.49 lb. per sq. in. of furrow section, a difference of 21 per cent. In another field and with another tractor and another plow, the draft was 8.73 lb. per sq. in. in one soil and in the adjoining soil it was 9.59 lb. per sq. in. of furrow section, a difference of 10 per cent.

These figures only indicate the difference in the draft of the plow and do not in any way show the difference in the energy required to move the tractor over the ground. For instance, in a good, hard stubble field, the tractor moves over the ground with a minimum amount of energy. Under such conditions the tractor should develop an ideal amount of horsepower on the

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drawbar, while in another field or while in the same field a few days after a rain when the soil is in good plowing condition, the ground would be so soft that the tractor would expend a large proportion of its energy in moving itself across the field. At the same time the ground might be sufficiently soft so that the plows would not require a great amount of energy to draw them through the soil. Under such conditions it is apparent that the tractor would be working at a great disadvantage, for a large percentage of the engine power would be devoted to moving the powerplant across the field and not to plowing the soil.

Another consideration disclosing at once the impracticability of testing tractors under field conditions is the fact that, due to climatic conditions, tractors must be tested in the same field having the same soil throughout and by the same operators. This would of course be impossible, for about 265 different tractors are being manufactured in the United States. Should these tractors average 10 acres per day, approximately 2650 acres of land identical in composition, moisture and topography and sufficient apparatus and engineers to make all tests in one day would be required.

Drawbar Horsepower Tests

Some manufacturers have felt that their tractors should not be tested for drawbar horsepower but for the number of plows or plow-disks they could draw, or by the size of the ensilage cutter, corn sheller or threshing machine they could drive. At first thought, this might be satisfactory from the farmers' standpoint but, because plows have such different drafts and ensilage cutters, cream separators, corn shellers and wood saws require such a varied amount of power to drive them, no exact comparison could be made. Horsepower is about the only legal unit for measuring power and for this reason it would seem advisable, if possible, to measure the drawbar horsepower of all these engines with the standard unit. To do this the board devised the apparatus described below which has been tried out in several preliminary tests, is now ready for official tractor testing and will be so used as soon as the summer season begins.

The drawbar horsepower tests decided upon by the board are only two in number. One is a 10-hr. test at the rated load of the tractor to be made with the gov-

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ernor set as in the first brake-horsepower test and other tests already mentioned. This will show whether the tractor will or will not continuously carry its rated drawbar load on drawbar work. The other test is to determine the maximum horsepower of the engine. This will consist of a series of short runs with the load increased for each run until the engine is overloaded or the drive wheel slips excessively.

It may also be well to give consideration here to other apparatus that was studied while determining the rules for testing. One piece that was given very careful consideration, and for which the Agricultural Engineering Building was planned is that consisting of large drums mounted upon pedestals, upon which the tractor wheels could be placed and held in position. The tractor, while driving through its own wheels, would in turn revolve the drum and brakes which were to be used to absorb this power. To measure the tractive effort a recording scale or dynamometer was to be placed behind the tractor. Such a scheme of testing would measure the efficiency of the gears and the economy and power of the engine. However, it would not indicate the power of the tractor because the plant would not be moving through the field and no energy would be required to drive the front wheels. It would be ideal for the tractor as there would be very little slippage between the tractor wheels and the surface of the drum. It was decided that this device would make an excellent apparatus for laboratory tests but that it would be of no value in measuring the power that the tractor would deliver to the machines which would be used by the farmer.

Another and similar scheme considered was to jack up the rear end of the tractor and bolt drums to the drive wheels which would absorb the power in a manner similar to that of the apparatus previously described. However, this scheme was abandoned for the same reason given in that case.

The Testing Course and Car

It would seem that about the only plan that can be devised for measuring the power delivered to the drawbar of a traction engine in the field is some form of standard field condition. This is practically what was worked out by the board. The field where the tests will

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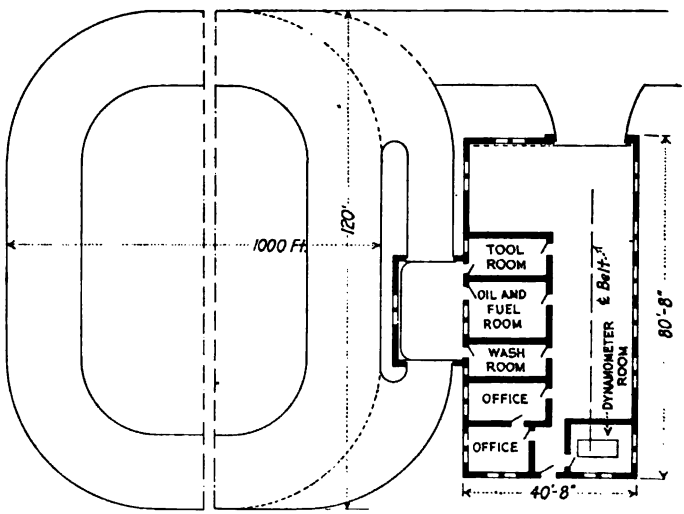
be made consists of a ½-mile roadway similar to a race course. However, the surface of this tractor course is composed of about six parts of cinders and two parts of loamy clay. It was at first thought that the cinders alone would make an excellent surface which could be held at a uniform consistency. However, after the cinders had been placed on the course and tractors had been driven over them for a week or 10 days, it was found that they did not bind sufficiently, so the cinders were plowed up and with them about 2 in. of the soil beneath. This mixture was very thoroughly pulverized with disks and alfalfa renovators, then it was packed down and after about a week's trial was found to give very satisfactory results. It can be kept of uniform consistency by the use of sprinklers and rollers during the hot, dry season, and the rainy seasons would of course keep the track soft and not too compact. Before the winter season began and after this course has been driven over by two or three tractors continually for about 10 days, the track was then in a somewhat pliable condition and very much resembled a stubble field when in normal condition for plowing.

The board of engineers spent considerable time working out some plan for absorbing the power of the tractor on this cinder course. Stone-boats were considered,



TRACTOR TESTING COURSE AT THE UNIVERSITY OF NEBRASKA

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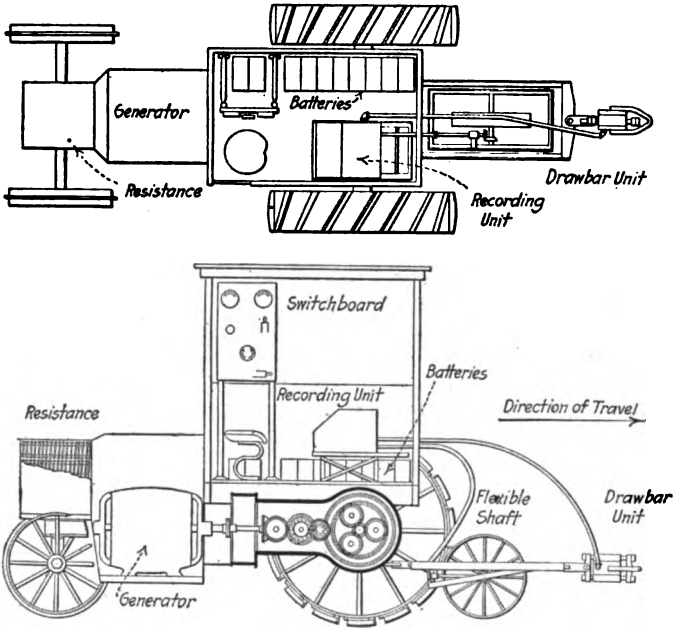

PLAN AND ELEVATION OF TRACTOR TESTING CAR

but it was felt that they would not keep the engine load constant. Dead tractors were then considered, but here again the difficulty entered of maintaining a constant load on the engine under test. Finally, the idea was conceived of removing the engine. the tank and the radiator from the traction engine and inserting in their place an electric generator with the necessary resistance for absorbing the energy it developed, and a design was then worked up.

This piece of apparatus, including the traction dynamometer, is known as the Nebraska dynamometer car. It is composed of an Illinois tractor chassis with a Foote transmission, an electric dynamometer placed in the frame in place of the engine and an electrical resistance substituted for the radiator. Between this chassis and the tractor to be tested a Gulley dynamometer with a rebuilt frame for carrying the driving wheels was placed. Where the engine cab is ordinarily located there is now a place for the operator of the dynamometer

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the Gulley dynamometer and the storage batteries for the generator and the electric lighting outfit complete the equipment. To avoid any danger that this outfit will rear up at the front end the tractor is drawn backward. The direction of energy is thus put into the gears in the same way as was designed for the tractor when driven by its engine.

This apparatus has performed better in all preliminary tests than was thought possible when it was first designed; the only point now in doubt about its perfect success is that it requires a little more power to draw it over the cinder course than was contemplated. Whether or not the car will require too much power for the small tractor, is still a question at this time. However, it is believed that the gears will soon "limber up" and thus the apparatus will draw easier. One interesting element already noticed in the use of this dynamometer is that slippage of the wheels can be detected. This is because the record on the dynamometer recording mechanism shows a line almost perfectly straight when the tractor and the dynamometer car both have smooth wheels and neither unit is slipping. However, when the lugs are placed on either the tractor or the dynamometer car or both the line is very wavy, and when the load on the tractor and on the dynamometer car is sufficiently great to cause slippage, the line is made up wholly of zig-zag marks. Because of this condition the operators of the dynamometer car will have a directly visible indication when either the tractor under test or the dynamometer car itself is slipping.

All of this apparatus can be bought in the open market and this cinder course can be duplicated anywhere in the United States, so that this combined plant makes an admirable piece of apparatus for testing tractors. Other plants can be installed and a comparison of the results at the various plants can be readily made.

The University of Nebraska has already spent some $30,000 for this apparatus and for a building in which a large portion of the tractors will be tested. Test work next spring will decide whether or not we have erred in our design. However, it is believed that the apparatus will work out admirably and that the results obtained from these tests will be of value not only to the farming public but to the tractor manufacturers. It is also hoped that the apparatus will be sufficiently

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practicable and of sufficient value to tractor manufacturers so that they will duplicate and use it at their plants. The University of Nebraska will be very glad to furnish complete drawings and specifications to anyone desiring to make a study of this apparatus and its use.

THE DISCUSSION

E. A. JOHNSTON:—I am familiar with Professor Chase's operations and believe that his plan of testing tractors will prove very satisfactory and be adopted generally. Several States are considering laws to protect the farmers and others have enacted such legislation. I believe in this and that if the prominent tractor manufacturers would cooperate by testing their tractors practically and adopt a standard method of rating, similar to the one adopted by Professor Chase, this would forestall much of the undesirable proposed legislation. I hope that all who are interested in the future of the tractor business will cooperate to secure a standard method of rating tractors.

D. BAKER, JR.:—Recently, a manufacturer gave no tractor rating and said he was awaiting a test by the State of Nebraska. Can a manufacturer advertise his tractor ratings, after testing, as certified by this State?

PROF. L. W. CHASE:—The Nebraska Legislature appropriated no funds for this tractor testing. The regents of the University of Nebraska supplied the money for the first year's work. As a result, we can test any tractor independently of the Nebraska tractor law. If any manufacturer should desire such a test, or, if we should desire to make any test for the manufacturer with his approval, such tests can be made on this apparatus independently of this law and the results may or may not be published, depending upon the arrangements made with the University of Nebraska. Relative to the official tests we are required to make and with which the tractor manufacturers are required to comply before they can sell tractors in Nebraska, the law says:

> The report of the official tests shall be posted in the agricultural engineering department of the University and in such other places as may be designated by it. The same shall be incorporated in the annual report of the State Railway Commission, provided that no tractor company shall use the results of said tests in such manner as would cause it to appear that the State university recommended the use of any particular model

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of tractor, in preference to any other type or model. It will be unlawful for anyone to publish such extracts without publishing the entire report.

A. B. BROWNE:—I have done much drawbar testing on drums but I believe that method would scarcely be applicable to tractor testing.

PROF. CHASE:—Professor Chatburn, of the University of Nebraska, has done considerable work along this line as it applies to highways.

ARTILLERY MOTORIZATION

By George W Dunham[1]

Motorization, as developed during the war, is stated as the greatest single advance in military engineering since the fourteenth century. Excepting about 66 per cent of the 77-mm. guns in the combat division, all mobile weapons of the United States artillery are motorized and complete motorization has been approved. The history of artillery motorization is sketched and a tabulation given of the general mechanical development in artillery motor equipment to May, 1919. Caterpillar vehicle characteristics are next considered in detail, followed by ten specifically stated problems of design which are then discussed. Five primary factors affecting quantity production, successful construction and effective design, in applying the caterpillar tractor to military purposes, are then stated and commented upon. A table shows specifications of engines used by the Ordnance Department and three general specifications for replacing present engine equipment are made. Ways and means of modifying present equipment are presented and the findings of the Westervelt Board that studied armament, calibers and types of materiel, kinds and proportion of ammunition and artillery transport methods are given in an appendix.

The Ordnance Department, through the chief of its technical staff, Col. C. L' H. Ruggles, has requested me to lay before you the problem of artillery motorization, and to solicit your interest, assistance and moral support in working toward its solution. Motorization as accomplished in the recent war could hardly have been

[1] Consulting engineer, Militor Corporation, Jersey City, N. J.

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effected without the assistance of this Society, which represents almost 100 per cent of the automotive engineering talent of America. Recognizing the necessity of continuing this motorization movement and the fact that much of this development has been accomplished by the creative ability of the members of the Society, it is the object of this paper to attempt to interest further those who have already aided this development and to arouse the interest of those who have not yet come in contact with the special problems of artillery motorization and cross-country mechanical transport in general.

Without question, the greatest single advance in military engineering since the fourteenth century is that of motorization as developed during the recent war. From the first authentic record of the existence of the cannon, reference to which appears in the journal of the city of Ghent, in 1313[2], up to the highly refined field gun and cannon of 1914, the two fundamental ideas kept in mind by military engineers in designing cannon have been to secure the maximum range and hitting power consistent with the mobility limitations of horse transport. It was only in 1914 that the United States considered the art sufficiently developed to warrant the hope of successful artillery motorization. In 1916 a fully motorized medium heavy battery was organized in this country and the first fully motorized artillery regiment in the world, the Ninth Field Artillery, in Honolulu. This removed the incubus of lack of mobility that had limited the ordnance engineer in design and handicapped artillerymen in battle from the days of catapults.

Since that time, and particularly during our participation in the great war, military requirements, as interpreted by leading ordnance and artillery engineers, have so changed the conception of mobility, that to date, with the exception of about 66 per cent of the 75-mm. guns in the combat division, the motorization of all mobile weapons of the United States artillery is an accomplished fact, and a recommendation for the ultimate motorization of those not now motorized has been approved.

In taking this big step forward in such a short time, and particularly because of the exigencies of war, it was impossible to make the design of the vehicles involved as complete or as consistent as could be desired, it being necessary to use the equipment most quickly available

[2] "Item; in this year was the first discovery of the use of cannon by a monk in Germany."

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and to adapt it wherever possible to that used elsewhere in our Army. Thus, there are certain discrepancies in design to which your attention will be directed later. It is the function of this paper to get the members of this Society, who have helped to accomplish this remarkable forward step in military engineering, to help iron out these discrepancies, maintain interest in the problem of motorization and thus make our country, through its mechanical skill and inventive ingenuity, possessed of the best and most scientifically-equipped army in the world.

In connection with the solution of a problem of this kind where the skill of the civilian engineer is bent toward solving a military engineering problem, there are two important relationships to keep in mind: (a) the influence of the present state of the art of automotive engineering upon the military problem, and (b) the influence of the development of the military problem upon the art itself. This latter conception in the case of artillery motorization is highly important.

The war has demonstrated to us the wonderful possibilities of the caterpillar tractor. This construction met with sufficient commercial resistance in the past to retard its development somewhat. There have been a limited number of manufacturers who were interested in perfecting this type. One of the big factors in winning the war was the basic principle or the idea which resulted in the design and creation of the "tank," namely, the caterpillar or track-laying form of construction. This type had, before the war, made possible agricultural accomplishments under conditions that could not otherwise have been met. It is now recognized as an essential means of transportation in logging camps, oil fields, mines, cane and rice fields, etc. As the art of caterpillar traction advances for military purposes, so will these other uses be elaborated and peace-time industrial engineering will thereby be made to advance.

History and Advantages

Before approaching the technical factors involved in the problem of artillery motorization, it will be best to provide a perspective by roughly sketching the history of artillery motorization. As stated before, range and hitting power have been from time immemorial the two obviously desirable cannon characteristics. As one army

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has made progress in these two factors, others have taken steps to offset them, so that the various big-gun equipments of all armies among the major powers is at any one period a more or less understood and fixed proposition. It was only during this war, in which the strain was so great as to necessitate reinforcing men and animals by every means which engineering, science and machinery could provide, that substitutes were finally

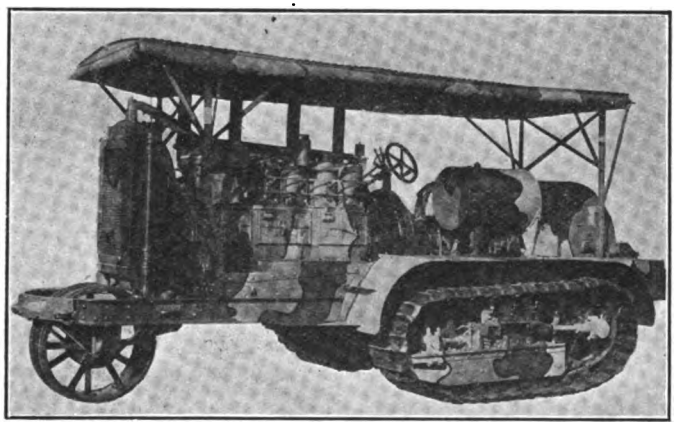

FIG. 1—120-HP. AMERICAN-MADE CATERPILLAR USED BY BOTH ALLIED AND CENTRAL POWERS TO HAUL GUNS OF LARGE SIZE

found for the animals which have, since the dawn of history, limited the mobility of armies. Only a moment's thought need be given to the fixed limitations of such animals; to their proneness to disease and vulnerability to climatic changes, gas and bombs, as compared with mechanical transportation; to the necessity of feeding them whether they are working or not; to the extreme care necessary to protect their health, and to the limitations in the length of their working period. Mechanical transport can be operated for long periods without rest, and any "sickness" can be cured within a few hours. The motorization of one 155-mm. howitzer regiment saves 1440 horses and 400 men. One tractor for this howitzer is the equivalent of 10 horses, and yet it is so compact that when packed it occupies but 360 cu. ft. The horses in a regiment equipped with this caliber of gun consume daily 36,000 lb. of forage, whether the animals are at work or idle. The same regiment with its equipment

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motorized consumes but 29,000 lb. of fuel, oils and greases, when moving 50 miles, which represents a 2-days' march for such a command in a period of vigorous activity and 10 days of average war movement. Furthermore, it stops this consumption when idle and there is a corresponding saving in personnel. Tractors are far more easy to "camouflage" than horses. A shrapnel burst which will kill every horse with a gun will usually leave one of these armored tractors uninjured.

FIG. 2—TRACTOR HAULING HEAVY GUN SHOWING ADAPTABILITY TO CROSS-COUNTRY TRANSPORTATION AND NEED FOR LOW UNIT PRESSURE

When France and Germany went to war, the Germans used a large American-made tractor (See Fig. 1) which they had purchased prior to the war to move the great Skoda guns from Austria into Belgium. France and England used this same make of vehicle for their heavy equipment, but at that time and even when the United States first went into the war, the policy of France, England and a considerable percentage of American military opinion were against general artillery motorization. The belief in the possibilities of motorization on the part of certain leading spirits in the ordnance and artillery services, combined with the growing pressure of military requirements, changed this opinion completely. These factors, combined with the able assistance of the members of this Society, gave motorization its real impetus and made America the leading factor in this phase of war engineering. The carriage division of the Ordnance Department in particular deserves great credit for the manner in which it expanded to meet the fast-changing conditions and the method in which the whole problem was handled.

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FIG. 3—A 10-TON TRACTOR PULLING A 4.7-IN. GUN AND CAISSONS WEIGHING 17,000 LB. IN THE NOVEMBER 1917 TEST AT ROCK ISLAND NEGOTIATING ROCK PILE

In the extracts from the Westervelt report which are given in the Appendix, it will be noted that under the guidance of the Ordnance Department, through its tank, tractor and trailer division, the following general mechanical development with respect to artillery motor

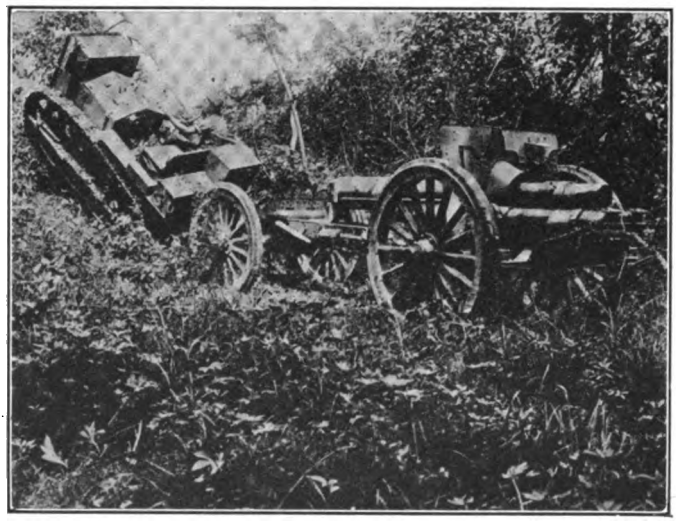

FIG. 4—A 2½-TON TRACTOR PULLING A 4.7-IN. GUN AND SHOWING THE NECESSITY FOR THE ENGINE FUNCTIONING ON A STEEP INCLINE

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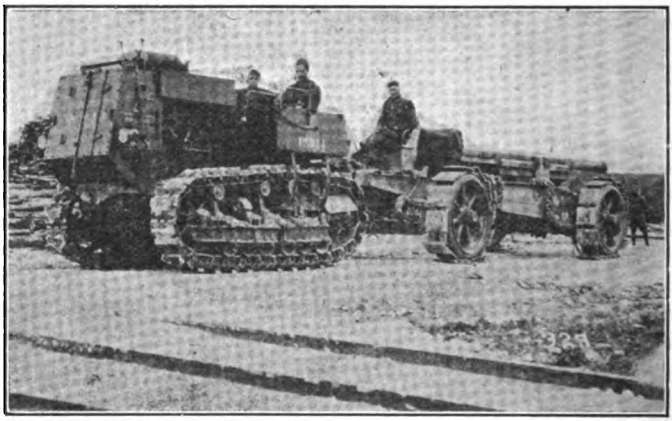

FIG. 5—A 10-TON ARTILLERY TRACTOR PULLING A 155-MM. GUN

equipment had been accomplished at the date this report was submitted:

(1) An efficient 10-ton artillery tractor for pulling heavy gun loads had been designed, tested and contracts for 2800 had been placed, of which 933 were in France

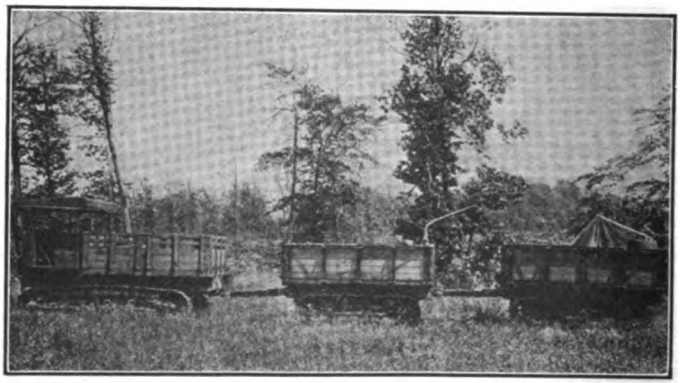

FIG. 6—TRACTOR CAISSON PULLING CARGO CARRYING TRAILERS WEIGHING 3 TONS EACH

(2) An efficient 5-ton artillery tractor for pulling medium gun loads had been designed, tested and 4000 were in production, of which 1018 were in France

(3) Efficient heavy mobile repair shops had been designed, tested and 17 shops of 2 sections each put

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into production, one of which was in operation in the occupied zone of Germany

(4) An efficient artillery repair truck had been designed, tested and 420 of 1332 under production were in France

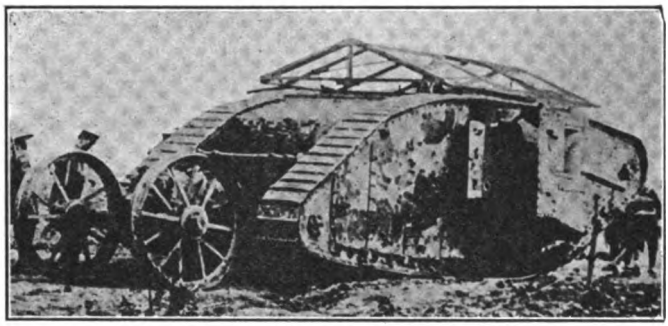

FIG. 7—EARLY BRITISH TANK USING COMBINATION OF WHEEL AND TRACK

(5) An efficient 3-ton four-wheel-drive truck had been designed, tested and adopted as standard for use in the Army

(6) Caterpillar tracks to replace wheels on certain heavy guns

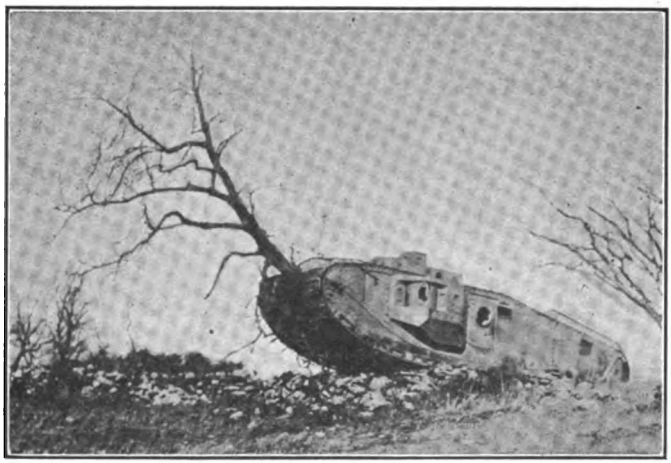

FIG. 8—MARK VIII, A LATE DEVELOPMENT IN TANK CONSTRUCTION

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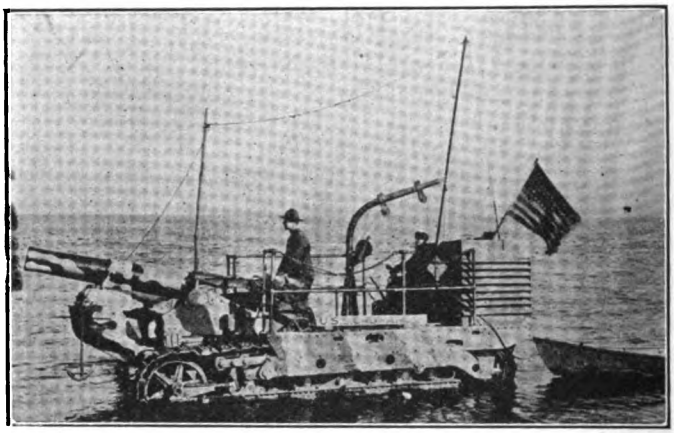

FIG. 9—SELF-PROPELLED GUN MOUNT SHOWING ABILITY OF PRESENT CONSTRUCTION TO OPERATE ON SUBMERGED GROUND

(7) The following had been designed, built and were being tested:
- (*a*) 2½-ton tractor
- (*b*) Heavy motorcycle for artillery
- (*c*) Self-propelled gun mounts for various weapons
- (*d*) Cargo-carrying caterpillars or tractor caissons
- (*e*) Cargo caterpillar trailers

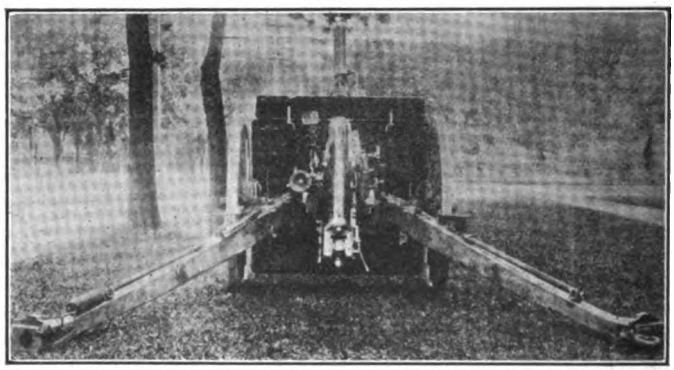

FIG. 10—1918 MODEL OF 8-IN. GUN
While fundamentally the same as the earlier guns note great improvement in construction and means of control

It can be stated with respect to (1), (2) and (3) that the United States is far in advance of all other world powers.

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While some of these vehicles may be open to criticism as to various details, all of those put into production are good practical mechanisms that function satisfactorily.

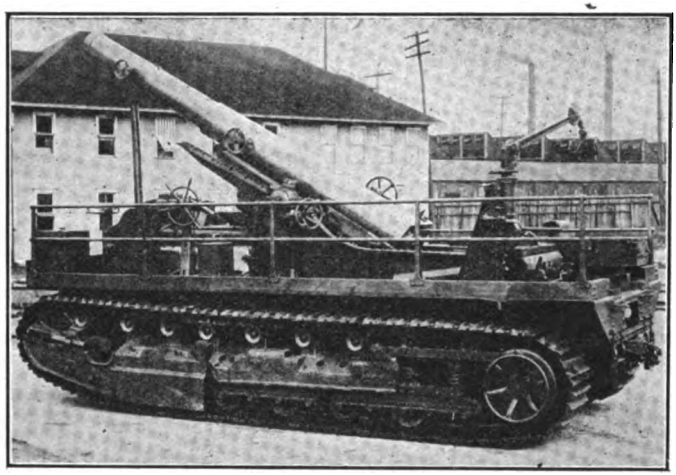

FIG. 11—LARGE HOWITZER ON SELF-PROPELLED CATERPILLAR MOUNT, THE LATEST DEVELOPMENT IN MOBILE ARTILLERY

As previously mentioned, the necessity for haste prevented a complete and consistent design, which explains the discrepancy indicated in Table 1 with regard to

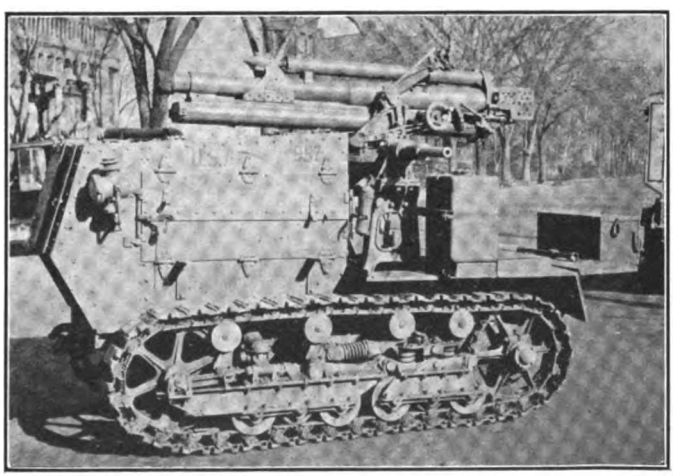

FIG. 12—READY ADAPTATION OF 75-MM. GUN TO 5-TON TRACTOR MOUNT

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excessive power in some vehicles and the lack of consistency in the type of unit used and its design. The commercial product of an American tractor manufacturer was used as the basis of these designs, and upon this were installed various available power units which, although not designed for this particular type of service, nevertheless functioned satisfactorily.

Caterpillar Vehicle Characteristics

In order that you may see the work that has been accomplished in this manner, various illustrations have been included with this paper showing the more impor-

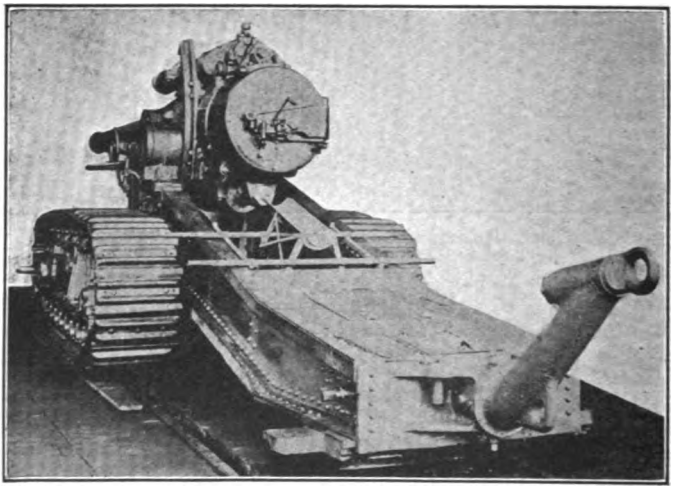

Fig. 13—A 7-In. Naval Gun Adapted to Caterpillar Tracks Making Transportation Off Roads Possible

tant pieces of equipment that the tractors have to handle (see Figs. 2 to 6), as well as the tractors themselves. The progress made in the development of the tank can be seen by comparing Figs. 7 and 8, while types of self-propelled gun mounts are shown in Figs. 9 to 13. Fig. 14 shows the adaptability of the tractor to military operations.

While this paper deals primarily with the use of caterpillar traction in artillery motorization, it must be appreciated that many wheel types of vehicles, such as the mobile repair shop (see Fig. 15), various trailers (see Fig. 7), etc., are a necessary part of the artillery motorization requirements and are today in a stage of develop-

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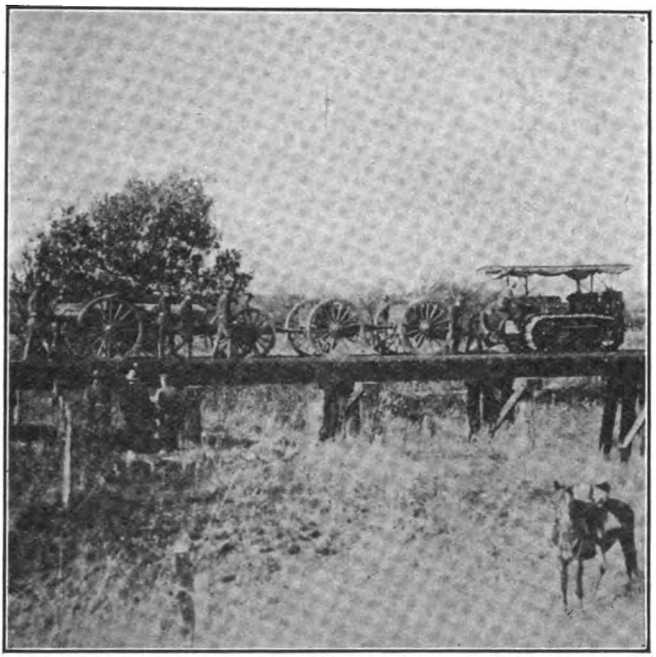

FIG. 14—ADAPTABILITY OF TRACTOR TO MILITARY OPERATIONS ILLUSTRATING GOOD WEIGHT DISTRIBUTION AND ABILITY TO CROSS RAILROAD TRESTLES WHERE HORSES COULD NOT GO

ment equal to that of the caterpillar traction development.

Before taking up some of the more important principles of caterpillar application to military requirements,

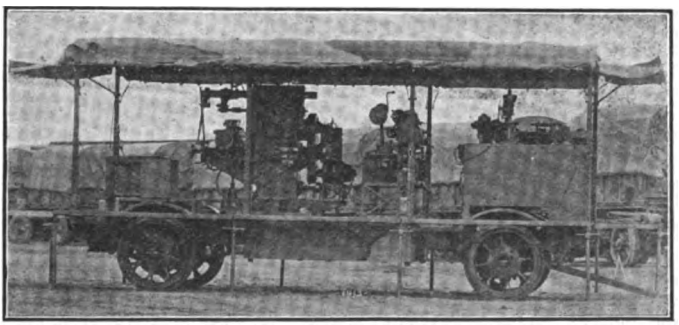

FIG. 15—MILLING MACHINE TRAILER, ONE OF THE MANY VEHICLES COMPOSING A HEAVY ARTILLERY MOBILE REPAIR-SHOP COMPANY

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I wish to make it clear that this paper does not attempt to indicate the final solution, but states the problem as it is known today. It is to be hoped, however, that a statement of the problem and of the requirements and present conditions will result in many valuable papers and much discussion.

A more or less conventional caterpillar tractor construction is here described for the benefit of those who are not familiar with this type of vehicle. Fig. 16 is a diagrammatic sketch of one of the caterpillar tracks and supporting mechanism of a military tractor. The engine and operating mechanism is carried in a chassis frame which is supported on a number of small wheels or truck rollers that in turn run on an endless belt or flexible track which acts as a medium for distributing

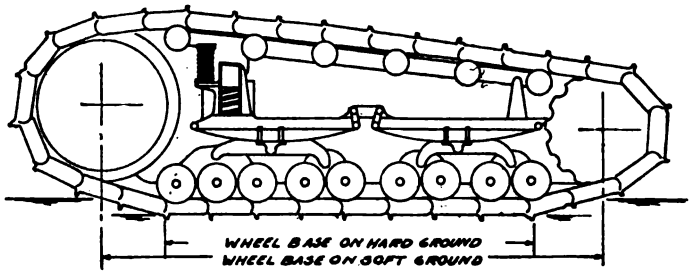

FIG. 16

the weight of the vehicle over the area of contact of the track with the ground. The track itself is supported on two larger rolls or sprockets, one of which is power actuated, thus making a vehicle construction having in effect elongated wheels, with a large wheel or track area in contact with the ground and resultant low unit pressure.

The unit pressure of the track in contact with the ground is much lower than could be obtained with the more simple wheel construction and is the prime reason why this type of vehicle is capable of better performance under extremely adverse ground conditions. Roughly speaking, the static unit pressure of an average-size man is about 6 to 8 lb. per sq. in., this pressure increasing by 100 per cent when he lifts one foot to walk. That of a good-sized horse will be found to be about 16 to 18 lb. per sq. in. staticly and more than twice that in action.

Referring to Table 1, the highest unit pressure shown, in the data tabulated, is less than 7 lb. per sq. in. on soft

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TABLE 1

Vehicle	Gross Weight, lb.	Pressure per sq. in.		Drawbar Pull lb.	Drawbar Pull in Percentage of Total Weight	Maximum Speed, m.p.h.	Engine			
		Hard Ground No Penetration	Soft Ground 5-in. Penetration				Make	Number of Cylinders and Dimensions, in.	Piston Displacement, cu. in.	Governed Speed, r.p.m.
2½-ton Tractor	7,700	40.8	5.53	4,280	55.6	12.00	Cadillac	8–3⅛x5⅛	314	2,000
5-ton Tractor	10,500	24.5	4.90	8,100	77.1	7.87	Modified U. S. A. Class "B"	4–4¾x6	426	1,280
10-ton Tractor	21,500	29.1	6.70	13,650	63.5	4.19	Holt	4–6½x7	929	600
3-ton Tank	6,700	8.4	6.22	3,760	56.1	7.76	Ford[3]	4–3¾x4	352	1,700
6-ton Tank	14,500	6.8	4.70	11,300	77.9	5.45	Buda	4–4¼x5½	312	1,300
Mark VIII Tank	80,000	13.5	5.45	75,700	94.6	5.20	Modified Liberty	12–5 x7	1,649	1,400
Mark VII Tractor Caisson	20,000	23.0	5.53	16,180	81.0	7.87	Modified U. S. A. Class "B"	4–4¾x6	426	1,280

[3]Two engines used. Displacement is total of both.

ground. The general military specifications for vehicles of the caterpillar type state that for the future the unit pressure in soft ground with 5-in. penetration shall not exceed 5 lb. per sq. in., a condition which can very easily be met. A study of Fig. 16 will show that when operating on a hard surface, ignoring any raised traction surface or grousers, only that part of the track beneath the truck rollers will provide means of support. As the tractor penetrates soft ground, the area of contact is increased. The sketch illustrates this point for static conditions only, for obviously, if the vehicle moved ahead, unless the ground is unusually springy, the surface would be pressed down so that but little additional contact would be made available at the rear of the track. There is another condition, however, that enters into the problem where the tractor is used for drawbar purposes. The drawbar reaction, as will be shown later, increases the pressure on the rear truck rollers to such an extent that the rear springs are compressed, allowing the rear sprocket to come closer to, or even to touch, the ground, thus increasing the contact area at the rear end.

While there are practical limitations in the length of a track due to the effect upon steering, it is very easy not to exceed 5 lb. per sq. in. pressure in soft ground, for after the maximum permissible length of track has been reached, if the ratio between it and the weight to be supported is too high the track can be made of such width that a maximum pressure of less than 3 lb. per sq. in. can be obtained, providing that the slight additional weight is permissible. Taking all the factors into consideration, 4 or 5 lb. per sq. in. pressure is generally satisfactory and is easily obtained.

When low unit pressure is known to be desirable, the question immediately arises as to why the large end sprockets cannot be lowered so as to bring the entire track from center to center of these sprockets in contact with the ground at all times. This would be desirable and is practically the result obtained in soft ground, but on hard surfaces, the laying down and picking up of the track shoes under these conditions creates a mechanical vibration that becomes objectionable at high speed. Even with a very short-pitch track-link, the same condition holds good, whether the track-link is picked up and laid down by the sprocket engaging with the track-link pin, or whether the track rolls around a drum like a belt. Fig. 17 indicates the path of the center of a sprocket

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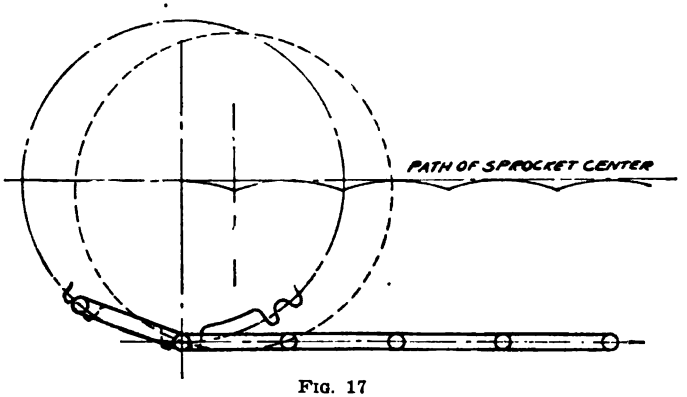

FIG. 17

where the track is lifted by a sprocket engaging with the pins. Fig. 18 shows the "digging-in" action of the end of the shoe when an attempt is made to roll the track around the sprocket drum like a belt. In either event, the necessity of providing clearance at the ends of the track is obvious. Therefore, on a hard surface the real "wheelbase" of a caterpillar vehicle is not the distance from center to center of sprockets but is roughly the center to center distance between the end track rollers.

For agricultural purposes slow speed over soft going is the usual requirement, but for military and industrial purposes, a possible high speed, approximately 12 m. p. h. or more, is desired. This requirement somewhat complicates the problem, in that such items as unsprung weight, proper spacing of truck rollers, suitable length

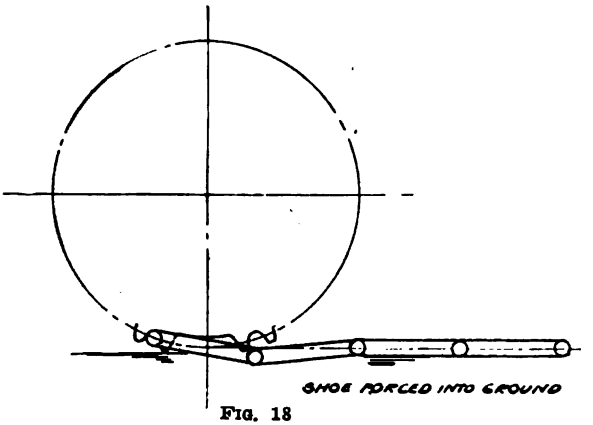

FIG. 18

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of track-links, track tension release, etc., assume increased importance.

Track tension release is accomplished in several ways, but in theory should the track clog up in such a way as to cause a foreign substance of considerable bulk to pass between the truck rollers or the sprockets and the track, some means must be provided to enable the track-supporting mechanism to yield, thus relieving the enormous strain which otherwise is liable to do severe damage. Fig. 19 shows such a condition. Here this strain is relieved by the downward motion of the sprung upper support of the track. This is illustrative of the

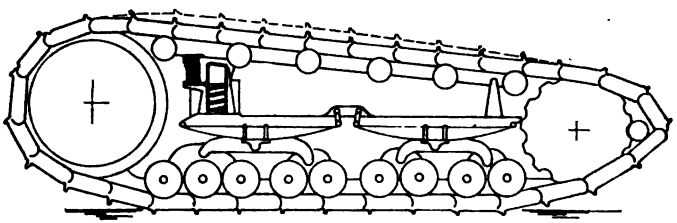

FIG. 19

construction used on the Renault tanks. It is necessary to support the upper part of the track to prevent undue slapping, and advantage is taken of this supporting mechanism to put an arch in the top part of the track, as shown in Fig. 16. The foreign substance passing through the track, as in Fig. 19, creates sufficient tension in the track so that the arch is straightened out, thus allowing the track to leave the sprocket at the rear end as shown.

It is well understood that there is a point at the bottom of a rolling wheel which is momentarily stationary, but it is rather difficult to visualize this fact. This condition is exaggerated in the case of the caterpillar track, as the lower part of the track is stationary with respect to the ground for a considerable period of time while the top part moves at twice the speed of the vehicle. This acceleration and deceleration of the track in relation to the ground, which is illustrated as a matter of interest only in Fig. 20, does not affect the stressing of the track, except as expressed in the centrifugal force due to the change of direction of the track in relation to the structure itself.

A caterpillar vehicle is usually steered by making one track operate faster than the other or by stopping one

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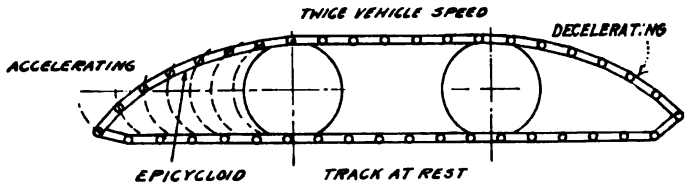

FIG. 20

track entirely and driving with the other. An idea of the effect of track length on turning can be obtained by reference to Fig. 21.

The most extreme condition is, of course, where one track is stopped and the other side driven. In the sketch the upper track has been stopped entirely and power applied to the lower one, in which case the vehicle will, theoretically, turn on a point beneath the center of pressure on the stationary track, the turning being accomplished by skidding the slowest moving or stationary track about this center.

PROBLEMS OF DESIGN

Without taking time for mathematical proof, it may be stated that for best results the length of the track for tractors should not be more than one and one-half times the tread, or the center to center distance between the tracks. For tanks and other self-propelled vehicles, a ratio of 2 to 1 is permissible.

The ideal proportioning of a caterpillar track can be stated as follows: The shortest possible track shoe to facilitate its being picked up and laid down, the largest possible diameter of truck rollers to negotiate the uneven surface of the track better and reduce rotational speed.

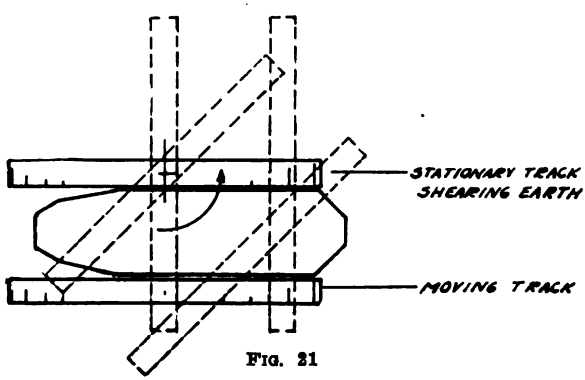

FIG. 21

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The spacing of these rollers should be about equal to the length of the track shoe. This distance should not be exactly equal but varied so that no two rollers will pass over a joint in the track at the same time. These conditions are impossible to meet ideally, as are most other problems in connection with automotive work, so, as is usual in such cases, the solution is reached through compromise, using a little longer track-link pitch and a somewhat smaller diameter of truck rollers. A combination which will operate most satisfactorily to all intents and purposes is one in which the truck rollers are spaced on a center distance of one and one-half times the length of a track-link, the variation of spacing, however, being maintained to avoid any number of rollers passing over track joints at the same time.

A caterpillar track may be likened to that of a railroad made up of very short rails but differs from it in that the rails are located as to position by the wheels of the vehicle instead of being secured to the roadbed. This, coupled with the necessity of what might be termed a positive tractive ability, the driving mechanism, the picking up and laying down of the rails or links, and the necessity of a greater number of smaller wheels on account of the shortness of the rails and the absence of the supporting ties on a graded roadbed, introduce a number of new problems, the more important of which can be listed as follows:

(1) The track material should be easily obtainable, tough and strong to resist wear and rough usage

(2) The track design should lend itself to economical production and assume such form as to readily clean itself of stones and mud

(3) Intelligent reduction of weight of the track-link perceptibly increases the life of the link

(4) The link joints should be made with pins of ample size to require the minimum of lubrication, if any, and to resist the driving loads and stresses caused by the tendency of the track to bend laterally in turning and in negotiating sidehills and rough going

(5) The joints should be arranged so as to avoid any "nut-cracker" effect. The opening and closing of any part of the joint, as the track works back and forth, tends to accumulate and crush small stones and dirt, seriously increasing the stressing of the working parts

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(6) The joint in the track rail between surfaces on which the truck rollers operate should be staggered or arranged so as to minimize shocks between the track and the rollers

(7) A reasonable amount of stock and sufficient clearance must be provided to allow for wear on the track rail, due to the action of the truck rollers

(8) It is advisable to load the track near its outer edges rather than at the center, to avoid a side-cocking or twisting action, resulting in undue loading of the track-link pins. This is apparently best accomplished today by the use of a double row of truck rollers. Attempts to compensate the track show that ball joints or hinged connections have not met with much success, owing to clogging up and increased weight

(9) The proper shape or form for the surface which comes in contact with the ground is of great importance, especially for military purposes. It should be arranged so that it will not damage good roads and still make the application of cleats or grousers unnecessary for ordinary soft going. Where grousers are required for maximum performance, they should be applicable with the minimum expenditure of time and effort. Some form of easily-applied calks are necessary for negotiating ice

(10) The track drive, necessarily positive, is usually accomplished after the fashion of a block or roller chain and sprocket. Here again care must be used to avoid clogging up with foreign matter, and provision made that the mechanism will clean itself to as great an extent as possible

The caterpillar track-link is a study in itself, about which much can be written. Although in its present state, when made of suitable material and properly designed, it functions most satisfactorily, in long and severe service it presents a very interesting problem, one worthy of the best efforts of the automotive engineer.

Considerable energy is being expended in the development of a combination wheel and caterpillar-tracked vehicle for military purposes; the wheels for high speed and the caterpillar to enable greater load carrying. The results to date are most gratifying, but I cannot help but feel that the ultimate answer for greater speed ranges for heavy-duty purposes will be in a purely caterpillar vehicle with light track shoes, a very small amount of unsprung weight, embodying the use of a

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considerable quantity of rubber or some other cushioning medium in connection with the rolling members and track.

A military caterpillar vehicle, either for drawbar or load-carrying purposes, should be provided with a four-speed gearbox. The first speed should be very low and give high torque; the second should provide a rate of travel from about 2½ to 3½ m. p. h. at the governed engine speed to harmonize with the rate of travel of a marching column; the third speed which should be from 7 to 8 m. p. h., is to be used as a general traveling speed where there are no special restrictions. This third speed is the maximum rate at which it is considered good practice, in the present state of the art, for caterpillar equipment, and especially the pieces which they now haul, to travel over long distances. An emergency speed of 12 m.p.h., or better, is desirable for short dashes, as for example where it is necessary to cross quickly places that are exposed to enemy fire, to bring up reinforcements, etc.

I am glad to note a tendency in truck and tractor construction toward lower first speeds. There are still too many who do not appreciate the remarkable advantages of this and its possibilities.

For satisfactory performance, a low emergency speed, giving high pulling power, is essential in any heavy-duty vehicle, for military or industrial purposes, regardless of whether it is a wheel or caterpillar type. Given a vehicle construction with sufficient area of ground contact to negotiate soft terrain, the problem becomes one of providing means for virtually gearing the tractive members to the ground surface. While the caterpillar is rapidly adaptable in this respect, as it permits the engaging of a larger number of cleats or grousers with the surface of the ground at one time, the tractive effort of the mechanism depends largely on the shearing strength of the soil in contact with the tractive member and immediately back of it. To obtain the best results, we are, therefore, confronted with the problem of using, to the best advantage, such strength as is to be found in this particular area of soil. As with any other material, the soil can be safely stressed to a higher degree if the load is applied gradually and uniformly. Careful investigation over a long period of time proves this statement, and it is found that with a very low gear ratio, both wheel and caterpillar types of vehicle

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have less breakage, require less area in contact with the ground and develop a greater drawbar pull for a given weight. In visualizing this emergency low speed for a military or any other class of heavy-duty vehicle, it should not be looked upon as a means of getting to the destination quickly but rather a provision which will prevent the vehicle being stalled under extreme conditions.

A caterpillar vehicle to operate satisfactorily over very rough going, where it is necessary to climb steep banks, cross ditches, etc., should have no projection outside a plane tangent to the front and rear end of the tracks and sloping at an angle of 60 deg. to the horizontal. It would be very desirable, from one standpoint, especially for military vehicles, to have the tracks extend a considerable distance ahead and behind the chassis; on the other hand, this would increase the weight of the vehicle without proportionate advantage and would probably adversely affect steering conditions to such an extent as to make it undesirable.

Weight is an important factor, especially in regard to vehicles of the lesser capacities, as it is desirable that they negotiate fixed and pontoon military bridges, and especially the light highway bridges common in this country. The following notes, indicating the different kinds and capacities of military bridges used by our army, are of interest:

(1) Fixed military heavy bridge, both steel and wood. Load, can take Mark VIII tank. Maximum width between curbs 132 in. Height of curb 8 in. Weight of Mark VIII tank 40 tons
(2) Present or intermediate type pontoon bridge, using standard equipment. Load, 5-ton axle loads with 10-ft. minimum separation
(3) Proposed new type of pontoon bridge of about twice the capacity of (2)

One of the great difficulties experienced in the operation of cross-country mechanical transport is in passing through water. This is of such importance that it has been specified that artillery vehicles shall be able to negotiate 5 ft. of water. This problem offers two solutions: that of partially submerging the vehicle and that of floating it. In this connection, it is worthy of note that water was the most effective protection against tanks that was used in the recent war.

The armor problem, from the engineer's standpoint, is more or less simple of solution; for, if the fact that the

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piece is to be protected is borne in mind, the necessary provisions for doing this can be very readily made.

One of the most important problems in connection with caterpillar equipment for artillery motorization is undoubtedly that of the proper location of the center of gravity. These vehicles have the ability to negotiate such rough terrain that a tentative military specification today requires that a tractor shall be capable of negotiating a 100 per cent grade without load and shall pull a trailer load equal to its own weight up a 60 per cent grade, if footing can be obtained.

Fig. 22 shows the tractor at rest or running on the level with a slight load. The ideal condition is to have a uniform load on all truck rollers at all times regardless of grade. The law of gravity, of course, makes this impossible. The overturning moment, due to the drawbar pull, is $D \times d$, where D is the drawbar pull and d the distance from the ground to the point of application of the drawbar. The overturning moment, due to the torque reaction and internal friction, which in turn is due to the tractive resistance, is $T \times r$. This resistance T is about 0.08 of the total weight of the tractor and the effective arm r is the radius of the driving sprocket. This makes the total overturning moment $M_o = D \times d + T \times r$. The stabilizing moment $M_s = W \times a$, where a is the horizontal distance from the center of gravity to the plane of the rear roller and W the weight of the tractor. These are the three external forces acting on the tractor and to have equilibrium M_s must be greater than M_o.

Fig. 23 shows the effect of a heavy drawbar pull on the tractor. In this case, the tendency is for the front rollers to lift off the ground and the rear sprocket to come down toward the ground. The stabilizing moment is now increased, its arms becoming a', and the tractor rocks about a point on the ground beneath the rear sprocket instead of about a point beneath the center of the rear roller as shown in Fig. 22. Fig. 24 shows how the stabilizing moment is decreased in ascending a grade. Fig. 25 illustrates the importance of keeping the center of gravity far enough back so that in descending a grade it will not fall outside of the front supporting contact of the track on the ground, in which case the machine is likely to overturn forwardly.

The effect of the height of the center of gravity is also of interest. Assuming the center of gravity to be

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the distance c from the ground and the angle of the grade α (see Fig. 26) then the moment-arm of the center of gravity becomes, $a \cos \alpha - c \sin \alpha$. From this you will note that as c approaches zero, or comes nearer to the ground, the length of the arm increases. In like manner the distance b (see Fig. 20) may be expressed similarly.

The problem as a whole is one of great magnitude and there is opportunity for application of our best

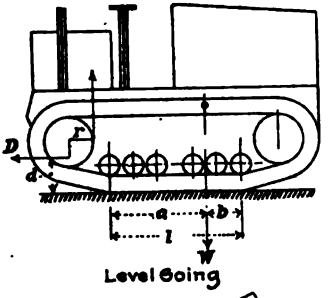

FIG. 22

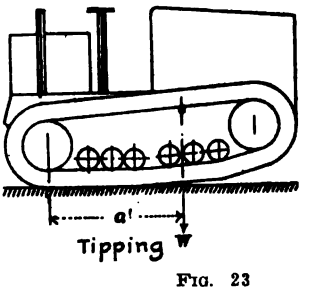

FIG. 23

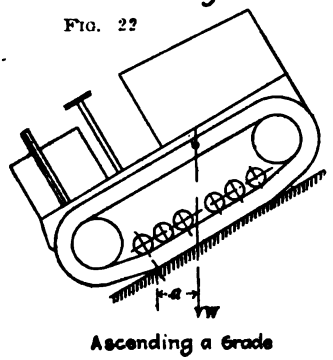

FIG. 24

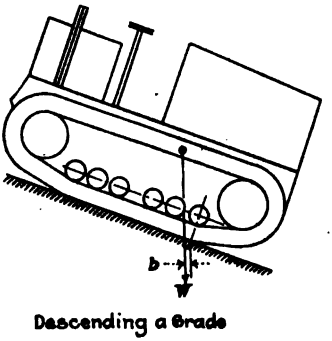

FIG. 25

In tipping the moment arm of the center of gravity increases
In ascending a grade the moment arm of the center of gravity decreases
In descending a grade the machine will overturn when $b = 0$

D = Drawbar
d = Distance between the ground and the drawbar or 28 in.
t = Reaction due to tractive resistance
r = Radius of the driving sprocket
W = Weight of the machine
a = Distance from the rear axle to the center of gravity
b = Distance from the front axle to the center of gravity
l = Wheelbase
M_o = Overturning moment $= D \times d + t \times r$
M_s = Stabilizing moment $= W \times a$
$M_s > M_o$

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ability to good advantage. In this paper I have merely touched the high spots, but if I have been successful in arousing your interest the desired result will have been accomplished.

Factors to Be Considered

In considering the application of the caterpillar tractor for military purposes, there should continually be kept in mind the fundamental rules affecting quantity production, successful construction and effective design. These may be expressed as follows:

(1) The proportions of the mechanism must be suitable to its use, as nearly correct theoretically as is possible and must function as intended
(2) The design must be such as to simplify the problem of production in every possible respect
(3) The materials used in its construction must not only be satisfactory for their purposes, but such as may easily be obtained in large quantities and uniform quality in times of stress and of such a nature as to be fabricated without undue effort or expense
(4) While original research is recognized as essential and by all means to be encouraged, nothing but thoroughly proved and accepted practice should be considered for production
(5) Interchangeability should be carried to the limit, particularly for military purposes, without, however, jeopardizing the success of the vehicle by imposing impossible requirements. Where possible, there should be interchangeability of units and parts between different *kinds* of vehicle, and as many similar parts as possible in a vehicle should be made interchangeable, thus reducing the number of different pieces

While the above rules are, of course, familiar to us all, they are repeated because of their prime importance in the design of military equipment, and because it is quite easy for one or more of them to be overlooked in connection with a problem of this kind.

It must be appreciated that the statement that tractors for industrial purposes are not good enough for military purposes is erroneous. The real facts of the case are that any tractor not good enough for military purposes is not good enough for industrial or agricultural purposes.

I believe that the close contact of the automotive manufacturer with the motorization problem in general

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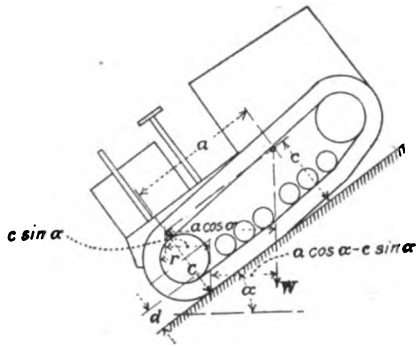

FIG. 26

Component of W along plane $= W \sin \alpha$
Maximum drawbar pull on the level $= 0.8\ W$
Maximum drawbar pull on a grade $= 0.8\ W - W \sin \alpha = W\ (0.8 - \sin \alpha)$
Stabilizing moment $= W\ (a \cos \alpha - c \sin \alpha)$
Overturning moment $= W\ (0.8 - \sin \alpha)\ d + 0.08\ Wr$
$W\ (a \cos \alpha - c \sin \alpha) > W\ (0.8 - \sin \alpha)\ d + 0.08\ Wr$

has given him much valuable knowledge and experience and that in many cases it has undoubtedly improved his product. On the other hand, it is to be hoped that military motorized equipment of all kinds can be developed so that commercial vehicles can, in their turn, be modified to be applicable to the military requirements. This is for two reasons. First, and of greater importance, it is beyond the ability of mankind, in the present state of the art, to develop a new piece of equipment as intricate as the motor car, truck or tractor, build it in quantity and put it into actual service, without going through a difficult and expensive period of learning the problem of production and overcoming unavoidable defects. It is only by putting military motor vehicles into actual production over a period of time that they can be made practically free from weaknesses or, to state it differently, it is only by the use of a commercial product, modified, if you wish, that our Army equipment can be made thoroughly satisfactory from the operation and maintenance standpoints. Second, it has been well proved, during our 18 months of participation in the recent war, that even with the resources of the entire country behind it no factory can be rearranged, tooled up for the production of a newly-designed vehicle and a satisfactory product obtained short of a period of time running into months, and then at an almost unheard-of expense. The use by the Army of vehicles already in

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production, would therefore make an immediate source of supply available at a much less emergency cost and would not disrupt the industry nearly to the breaking point. This principle is thoroughly appreciated by the Ordnance Department but, at the same time, the problems incident to using commercial vehicles for war purposes have seemed almost unsolvable.

The Ordnance Department, during the period of our participation in the war, used engines in some of its vehicles which conformed to the specifications given in Table 1. It has plans for the future which, when put into effect, will ultimately replace the present engine equipment with a series of powerplants, which it is estimated should be about as follows:

(1) A 60-hp. engine for use in 2½ and 5-ton tractors, self-propelled gun mounts and cargo carriers of corresponding capacities. The reason for the relatively less horsepower in the 5-ton tractor as compared with the 2½-ton unit, is that it is assumed to be a slower speed vehicle

(2) A 120-hp. engine for use in 10 and 15-ton tractors and any self-propelled gun mounts or cargo-carrying vehicles of like capacity, the loaded weight of which does not exceed 50,000 lb.

(3) Engines of 350 to 400 hp. for use in the heaviest types of tanks

These capacities are, of course, only estimates, but they give some idea of the tendencies in future military engine requirements.

Conclusion

This industrial problem and the other engineering problems are a few which are laid before you for solution. Can the military engineers modify their requirements and plans to meet a possibly modified method of procedure of the manufacturers, or can some scheme be developed whereby these two groups can get together in producing and using a commercial line of vehicles and units? Is it possible to take the design of an engine already in existence, or is it better to design a new one and to attempt to interest manufacturers to take it up and gradually put it into use in order that the type, size and design of engines may be consistent?

In any event, existing equipment must be modified to meet desired operating conditions, future possibilities and peace-time requirements better. This existing equipment must be studied over a period of time; it

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must be revamped and in some cases entirely redesigned in order that it may be produced more efficiently and fit in with the producing conditions of the automotive industry.

Congress must provide the authority and the means whereby this most necessary work can go on. Large sums of money and great engineering effort are expended annually by many of our large manufacturing concerns in the improvement and the development of a single product. Obviously, it is necessary for the Government to go to greater extremes in carrying out this important motorization movement, because in this there will be no direct competition to act as a stimulus and others will not undertake or continue the work if the Government does not.

The Society has been requested, and has already appointed, a committee of seven members to advise with the technical staff of the Ordnance Department.

It is hoped that those of you who have been active in similar work during the war will continue to give thought to the solution of the problems here outlined, and that others will also become interested to the end that all of us shall give our best efforts and moral support, as has been requested for the furtherance, not only of this most important military project, but also for realizing the commercial advantages that will evolve from it.

Let us apply to the solution of this big problem the same enthusiastic energy that was applied to the winning of the war, so that our country, through the cooperation of its automotive experts with its ordnance engineers, shall continue to lead in the art of cross-country mechanical transport.

Appendix

The Westervelt Board, so called after its senior officer, Brigadier-General W. I. Westervelt, consisted of a group of seven Army officers appointed Dec. 11, 1918, to make "A study of the armament, calibers and types of material, kinds and proportion of ammunition, and methods of transport of the artillery to be assigned to a field army."

After a thorough investigation, in both this and certain Allied countries, the report of its findings was made at Washington, May 5, 1919, and approved by the Chief of Staff on May 23, 1919.

The war has brought about no radical changes in

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motor cars. About the most that can be said on this subject is that certain commercial cars have shown greater strength of parts and ease of operation than others. They are, therefore, favored for military purposes.

When motor trucks were first used for military purposes the commercial types were naturally used. The two-wheel-drive type was the first to appear; later, to meet a demand for utilizing to the best advantage the full power, the four-wheel-drive type made its appearance in the commercial world. When the two types were tested in the early days of the Mexican expedition, real dependence was placed on the four-wheel-drive trucks, there being instances where whole trains of two-wheel-drive trucks were stalled. At a later date when the roads had dried and improved, the two-wheel-drive type made a better showing and came out with a better reputation.

However, the artillery is most interested in the type of truck that is best suited for bad road conditions. The United States Marine Corps, which has had to use motorized field artillery for some of its minor operations, adopted, after many tests, the four-wheel-drive truck to handle its artillery. Throughout the entire war the English, French and Russian governments, purchased considerable numbers of trucks driven on all four wheels, for use in their artillery service and, as late as July, 1918, the French made an urgent demand on the American Expeditionary Force for 300 such trucks. The four-wheel-drive truck has such power application and weight distribution as to assure movement of the vehicle if traction can be obtained even by one wheel.

Up to the fall of 1917, there had not been found a type of four-wheel-drive truck as refined in mechanical detail as some of the higher types of two-wheel-drive trucks. This was natural, as the development of the four-wheel-drive came later than that of the two-wheel-drive truck. However, the Ordnance Department undertook the development of a four-wheel-drive truck that would not have any of the defects of the four-wheel-drive commercial types. This truck was ready for production in May, 1918, and was recommended by a board of officers from practically every department of the service for adoption as the standard type of four-wheel-drive truck for the United States Army (see paragraph 30, War Department Special Order No. 91, dated April 18, 1918).

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In the opinion of the board, the four-wheel-drive two-wheel-steer type of truck is the only heavy cargo carrying wheeled vehicle which is adequate to meet artillery needs in the battery, battalion and the regiment as well as in the artillery ammunition train, and until a definite recommendation to this effect is approved, the artillery arm will be burdened with a heterogeneous mass of trucks whose use is confined almost entirely to good roads.

The following are extracts from the report mentioned, which are of interest as bearing on the subject of this paper:

> Mechanical transport is in such a state of development in this country that there is no need in dwelling upon its numerous advantages over animal draft. It is, however, pertinent to give a brief outline of the extent of its employment by foreign governments, while stating that the United States is far in advance of all other world powers in respect to self-propelled vehicles as applied to artillery transport
>
> *German* Wheeled tractors of the farm and road repair type, with low speed, great power and extreme weight for hauling heavy weapons. Wheeled trucks of the two-wheel-drive type with medium speed, medium power and normal weight, carrying anti-aircraft guns, directly and permanently mounted upon the chassis
>
> *Italian* Wheeled trucks, similar to the German vehicles as anti-aircraft gun mounts. Wheeled tractors of two-wheel-drive type, medium power, speed and weight for hauling heavy weapons
>
> *British* Rear-wheel-drive trucks, four-wheel-drive trucks and a limited number of the heaviest American commercial farm caterpillars for hauling heavy weapons
>
> It is noted that these three nations confined themselves, for the most part, to wheeled vehicles, which at once limits mechanical artillery transport almost entirely to good roads.
>
> *French* While using four-wheel-drive trucks of great power and mobility throughout the war, the French finally recognized, in 1917, the necessity and advantage of cross-country mechanical transport as evidenced by their development of platform caterpillars for carrying their 155-mm. howitzer mounted on its wheeled carriage, and for towing other heavier

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GENERAL SPECIFICATIONS

Vehicle	Draw-bar Pull, lb.	Cargo Capacity, tons	Speed, m.p.h. Minimum	Speed, m.p.h. Maximum
Caterpillar Tractors				
Tractor cart[4]	....	1/10	1	4
Tractor[4]	....	1/4	3	12
Tractor[5]	4,000	2½	3	11 to 12
Tractor[6]	7,000	5	3	8
Tractor[4]	10,000	10	3	6
Tractor[4]	15,000	15	1	5
Tractor caisson, Mark VII[5]	....	3½	1½	4
Tractor caisson, Mark VIII[5]	....	5	....	....
Trailers				
Caterpillar trailer[5]	....	3	....	....
Light caterpillar trailer[4]	....	1½	....	....
Wheel Type Vehicles				
Ordinary standard four-wheel drive[6]	8,000	3	3	12
Light four-wheel drive[4]	....	1 to 1½	3	15
Heavy motorcycle with sidecar[5]	....	¼	3	50
Trailers				
Trailer[6]	....	3	....	....
Trailer[6]	....	4	....	....
Trailer[6]	....	10	....	....

[4]Proposed.
[5]Under test and developing.
[6]Adopted.

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Application	Remarks
Caterpillar Tractors	
Wire reels; heavy machine guns; infantry accompanying gun	Operated by man on foot
Miscellaneous pack transportation; heavy machine guns; mountain guns; replaces horse for individually mounted men; wire reels	Replaces riding horse of individually mounted man
75-mm. gun; light field howitzer; reel carts	
155-mm. howitzer; 4.7-in. gun; 9.2-in. and 240-mm. howitzer, breaking into 3 loads	
8-in. howitzer; 155 G. P. F.; 9.2-in. and 240-mm. howitzer, breaking into 3 loads; salvage	
5-in. and 6-in. seacoast and 194-mm. guns; salvage	
Ammunition transport with battery; 155 G. P. F. tractor hauled or tractor mounted; army artillery	Replaces caissons in heavy batteries
.....	Not thought practicable, due to excessive weight
Trailers	
Ammunition transport with battery; 4.7-in. and heavier guns; howitzers	Replaces caissons in medium heavy batteries
Ammunition transport with battery; 75-mm. gun; light field howitzer	Replaces caissons in division artillery
Wheel Type Vehicles	
Army and corps artillery; all uses	
Divisional artillery; all uses, including ammunition trains	
Trailers	
.....	Transport of 10-ton tractors, etc., in heavy batteries

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weapons; of cargo-carrying caterpillars for ammunition and other supply purposes; and of self-propelled caterpillar gun mounts for heavier guns.

The superiority of the caterpillar over all other mechanical prime movers across country may be realized when we consider the essential features embodied in its construction. The frame supporting the powerplant with the necessary power transmission members is mounted upon small wheels. These wheels, instead of making direct contact with the ground, travel continuously upon a track, the rails of which are permanently mounted upon a flat, broad surface. This surface of tread corresponds with the sleepers or cross-ties of the railroad and is of such width as to secure very low unit pressures upon the ground. The track with its tread is formed into an endless belt which is driven by a sprocket identically as is the bicycle chain. The whole vehicle, therefore, may be said to constitute a wheeled mechanism which lays its own track as it moves over the ground. Further, by articulating the track and the frames or trucks which mount the wheels, accurate conformation to the varied ground surface is obtained, a feature which further insures traction. Again, the power is applied in such a manner that an individual drive is assured on each of the two tracks. With such a structure, movement is assured over very soft ground owing to low unit pressure, which is usually about 5 lb. per sq. in. The caterpillar can span wide gaps or ditches, or climb steep slippery grades. The grip on the ground or traction is secured by cleats or grousers which project to a height of approximately 3 in. from the surface of the treads. With the grousers removed the caterpillars do not seriously damage hard roads. The above advantages make the caterpillar the only logical prime mover to replace the team in draft.

The progress in artillery motorization is best indicated by the recommendations and results obtained by boards of artillery and ordnance officers. These recommendations were arrived at after long, careful study, test and investigation, not only in the laboratory but also in the field under simulated and actual war conditions. The authority in each case is given, together with the substance of the recommendation of the various boards.

Paragraph 51 of War Department Special Order No. 98, 1917, appointed a board to "consider the question of

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motor traction for field artillery." This board recommended

(1) Motorization of the 4.7-in. gun
(2) Motorization of the 8-in. howitzer
(3) Use of rubber tires on all field artillery material
(4) Formation of a pool of 30 artillery tractors for each combat division
(5) Sending a member of the board to France to investigate the motorization of the 6-in. howitzer

These recommendations were approved by the Secretary of War, and the several supply departments were directed to put them into effect.

The result of the investigation in France was paragraph 7, Special Order No. 83, General Headquarters, A. E. F., 1917, appointing a board to "consider and report upon the question of motor transportation for 6-in. howitzer materiel."

This board recommended

(1) Motorization of the 6-in. howitzer
(2) Retention of the divisional tractor pool
(3) Development of motor transport for artillery in all forms

These recommendations were approved by the Commander-in-Chief, A. E. F., in paragraph 15, cablegram No. 149, to the Adjutant General, Sept. 11, 1917, and the supply departments were directed to comply.

Paragraph 69, War Department Special Order No. 242, 1917, appointed a board to continue the work of the field artillery motor-traction board "to consider all questions of motor traction for field and heavy artillery."

This board recommended the motorization of

(1) The 6-in. howitzer
(2) The 4.7-in. gun
(3) The 9.2-in. howitzer
(4) The 240-mm. howitzer

The board further recommended

(1) Use of wheeled trailers in certain motorized organizations for rapid transport of the tractors
(2) Use and general requirements of the staff observation and reconnaissance cars

These recommendations were approved by the Secretary of War, and the supply departments were directed to take the necessary steps to comply therewith.

Based upon data collected by the above boards, the General Staff drew up tables of organization for motorizing the 155 G. P. F., and the 5 and 6-in. seacoast converted guns.

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An artillery board at General Headquarters, A. E. F., after practical test recommended

(1) Motorization of 50 per cent of the 75-mm. gun regiments in each division

(2) Motorization of the caisson companies of the ammunition train

These recommendations were approved by the Commander-in-Chief, A. E. F., in paragraph 1, cablegram No. 1771, Oct. 9, 1918.

Weapons of various sizes have also been placed on experimental self-propelled caterpillar mounts, namely, the 75-mm. gun, the 155 G. P. F., the 8-in. and the 240-mm. howitzer.

THE DISCUSSION

COL. C. L'H. RUGGLES:—The Ordnance Department is much indebted to Mr. Dunham for the presentation of this paper. It is continuously in debt to many prominent members of the Society, not only for the efficient assistance they gave in the motorization program throughout the war, but for the interest they have taken in the development of artillery motor traction now that the war is over. We must not lapse into a false feeling of security. Conditions in the world are far from settled. Many bitternesses must remain, particularly in the defeated nations. Russia is an unsolved problem. It is by no means impossible that new combinations of nations may arise to threaten the peace of the world again. Therefore, it is incumbent upon this Nation to keep itself prepared.

The problem can be resolved into two principal factors, the training of the man power of the Nation and industrial preparedness. It is the duty of every good citizen not only to do his share to improve the conditions under which we live but to see to it that proper laws are passed by our representatives in Congress to insure the continuance of real freedom and to deal adequately with new conditions as they arise. Each one of us must be prepared to defend our country, its institutions and its laws, by force of arms against foreign enemies or enemies within its own borders. How can we do this unless each of us has at least an elementary training in the scientific use of military arms under trained direction? Universal training will improve our young men physically; it will give many of them ideas of citizenship and discipline they would not otherwise have; and, with adequate indus-

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trial preparedness, it will provide a strong arm for our people which will insure them from aggression from any source whatever.

Of the two factors of preparedness, the one which furnishes the greater problem and of which unfortunately we hear the least, is the factor of industrial preparedness, the munitions problem. In a war between powers of the first magnitude, all the industrial resources of the nations concerned will be strained to the limit and, should the United States be involved, we cannot hope again to have allies that will hold the enemy while we get our production of war material started. Therefore, we must be prepared with a reasonable amount of munitions on hand, with designs of new materiel embodying all the latest improvements in the military art perfected and ready for issue to our private industrial plants at a moment's notice; and these designs should admit of quantity production in the shortest possible time after their issue. The Ordnance Department should be familiar with the capabilities and capacities for munitions production of the various plants throughout the country, have plans made showing the kinds and amounts of munitions to be produced at the various plants, and endeavor to keep the management of the plants and the engineers of the country interested in and informed as to the latest war material designed or being designed.

At present we are fortunately situated. We have a large amount of munitions on hand which are as modern as any used during the war. Our manufacturers are now familiar with the production of such munitions, and thousands of engineers throughout the country have served in the Ordnance Department, while thousands of others have aided in the production of munitions in the various plants throughout the country. But these conditions will change. Certain kinds of munitions, such as powders, explosives, fuses and grenades, will deteriorate, and must be replaced. Guns, gun carriages, tractors, tanks and ammunition will become obsolete through the development of new and improved types, and younger men will take the place of the engineers and manufacturers who have served the country in and out of the Ordnance Department during the war.

The technical staff of the Ordnance Department is charged with the duty of establishing and maintaining a liaison with the engineering societies of the country, to keep alive the knowledge of and the interest in indus-

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trial preparedness that now exists. It has made a most satisfactory beginning in this work with the Society of Automotive Engineers which, at the request of the Ordnance Department, has appointed a committee to consult with the Department and advise as to the suitability of its designs, not only with respect to military requirements but also with regard to the production features, as it would be folly to produce designs on paper that cannot be manufactured rapidly by commercial plants when emergencies arise. The appointment of this committee is an assurance to the Department that it will not unknowingly deviate widely in its designs from good commercial practice, and that through the members of the committee the Department will be kept advised constantly as to the improvements in the automotive art applicable to military types. This committee has already had two meetings with officers of the Ordnance Department; one at Washington, and the other at the Rock Island Arsenal and Peoria. Both meetings have been of great assistance to the Department and increasing benefit from meetings is expected as the Department progresses with the development of its new designs and the tests of experimental materiel. It is expected to hold joint sessions of the committee and officers of the Ordnance Department every two or three months.

J. L. BREESE:—Referring to Table I and the values given for the pressure per square inch on hard and in soft ground, are the surfaces dependent upon the amount of penetration?

COL. L. B. MOODY:—Yes. In Figs. 22 to 25 details are given. The shorter the contact with the ground, the easier the steering becomes. Generally speaking, while the pressure on some of these machines may run high on macadam roads, that is not an objection. Our general specification is to the effect that the vehicle shall not sink into the ground to an extent that will interfere with steering and that the ground pressure shall not exceed 5 lb. per sq. in. Some of the war vehicles reached 7 lb. per sq. in. This is not excessive; 5 lb. per sq. in. is about a fair compromise.

MR. BREESE:—Four speeds and maximum torque at zero speed are desirable. This suggests the steam engine. Has anything been done along this line?

COLONEL MOODY:—The steam engine was tried in one of the tanks with the idea of obtaining maximum torque with minimum horsepower. We continued the use of the

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mechanical transmission according to the consensus of the manufacturers' opinions.

JOHN YOUNGER:—The keynote of this paper is a plea that the lessons of the war should not be forgotten in times of peace, and that we should be preparing constantly for the next war. There will be a next war. During the last war a sword was hanging over us; as soon as this was taken away, the dollar took its place and all of us seem to be reaching out for that dollar, unmindful that the sword may return. We have a tendency now to forget Washington. We must overcome that. We must realize that the lessons learned during our connection in Washington must be remembered in times of peace, when we have time to think them out. They should be taken to ourselves and studied; we should keep not a fixed but a flexible policy, looking ahead and educating ourselves. The last war was a war of engineers; the next war will be a war of engineers. It will be a greater war, and it is only by the aid of engineers that the Army can meet the expansion necessary for war.

L. W. CHASE:—I believe that much greater sympathy should be shown toward the War Department. I was sufficiently close to the tractor section while in Washington to absorb many ideas on this subject. There should be some means whereby the farmer and the manufacturer can attain closer contact with the Ordnance Department, especially regarding the tractor situation. The tractor is an agricultural machine. The agricultural public absorbs this machine. I have hoped that some line of tractor manufacturing due to our war experience would be developed that would aid the agricultural public. I believe data are filed in Washington whereby the Ordnance Department could publish the results of many tests that it has made, through organizations similar to our Society. Even if the results of those tests caused the abandonment of the tractors under test, the results would aid the manufacturers who are now making or contemplate making track-layer types. I have used every opportunity to inspire greater public enthusiasm in the benefits now being developed by the United States Army for civilian purposes and I feel that we should all do this.

In the case of the Ordnance Department, working as it does day and night, through storms and mud, to develop its tractors, there must be many data relative to

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the comparative wearing values of various materials, the effect of weight on tractor tracks, etc. If this could be made available to the manufacturers, the expense of their learning what may be known already by the War Department could be avoided.

I think that the farmers will not demand over 4 m.p.h. from a tractor. They are sufficiently accustomed to trucks to demand speed from them, but they will use the tractor for field purposes only. Except for that point in the design of tractors and tanks, it appears to me that the Ordnance Department could utilize the agricultural and manufacturing fields in determining many wearing qualities. This agricultural application may seem visionary, but it might be made. I hope that funds will be made available so that the Ordnance Department can always be in advance of anything used commercially.

H. C. BUFFINGTON:—Ordnance requirements have constituted one of the greatest caterpillar-tractor problems. The industrial tractor business is very attractive, but the company I represent is designing its machines so that, in case of emergency, such parts as are necessary will convert the industrial tractor into the Ordnance Department type. Thus far we believe we have been successful, although there are many problems connected with caterpillar or track-laying tractors that are very vexing, such as differences in the center of gravity when climbing and when going down hills, unit pressure on the ground, resistance to turning, etc. These are very important and must be solved by a compromise that will suit war conditions. The track itself is the greatest problem today. Imagine a heavy railroad train passing over a rail and the rolling-out effect it has upon the rail. This may split the rail, although the train passes over it only several times daily. The track of the caterpillar tractor is subjected to this rolling-out effect continuously during its operation and some tractors operate day and night for weeks. The Ordnance Department is developing the track itself, as well as the tractor, and the engineers of this Society should do likewise.

G. R. PENNINGTON:—As one of the Ordnance Department engineers I wish to suggest a practical means of cooperation between members of the Society and that Department. Frequently those engaged in tractor design have promising ideas which, due to press of other duties

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or lack of experimental equipment, they are prevented from developing themselves. If these ideas are sent to the tank, tractor and trailer division of the Ordnance Department, they will be studied and, if believed practicable and applicable to military vehicles, this division may be able to carry out the actual development and test of such ideas. Full details of the studies made and the results obtained will be given, so that the originators will become as familiar with the possibilities of their ideas as though they had developed them at their own expense. The Government will at the same time acquire ideas useful in its design work and thus both will be benefited.

DENT PARRETT:—I understand that one of the objects of this paper is to bring out a discussion as to whether it is advisable for the Ordnance Department to develop its own line of engines or use the commercial engines. I have given the matter some thought. It appears to me that a commercial engine should be used. However, the larger size of tractor offers another problem. I know of no commercial firm using engines of a type which would be adaptable to it.

D. M. FERGUSON:—Investigations have been made with reference to the application of regular commercial engines to artillery vehicles. It has been found to date that it is necessary to make certain modifications to suit that application. Some manufacturers are making use of the knowledge gained during the war in the revision and designing of engines to apply to artillery vehicles, but in most instances those designs are merely experimental. Only one or two companies are actually building engines for artillery installation.

LIEUT.-COL. L. H. CAMPBELL:—There is one other point of development, self-propelled caterpillar gun-mounts. We take guns of various calibers, up as high as a 9½-in. howitzer, and mount them on a special form of tractor. The tractor must be of a special design on account of the heavy firing loads we have to care for. In the case of the 9½-in. howitzers, that load will run up in some cases as high as 200,000 lb. With our lighter guns, such as the 75 mm., the load is small, 17,000 lb.

Regarding the cooperation of this Society with the Ordnance Department, before I entered the Department I had the idea that the Ordnance Department knew it all and that they knew they knew it all. Since becom-

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ing a member of it I know its attitude is absolutely the opposite. Within the last few weeks we went out with a special committee of this Society for three days. I learned more from these men about this business than I ever knew before. I worked with ideas that I never dreamed of before. The Society can give us a thousand more of the same kind. We want them.

Regarding the engine proposition, the best thing the Ordnance Department can do is to tie up with some engine builders. If we could establish connections with some manufacturers and let them develop the engine for us, then, as improvements are made, such as another type of valve, they will keep our engines up-to-date. Thus, when twenty years pass and the next war comes, our engines will not be twenty years old. Let us tie up with the civilian manufacturers.

GEORGE W. DUNHAM:—There is a crying need for some workable scheme to provide a consistent and satisfactory line of engines that can be readily obtained for military purposes. I spent much time at Washington during the war and have seen the conditions as they exist, have talked with the men doing the actual work and appreciate the great magnitude of the problems they have to solve. There is still a big work to be done in connection with military motorization.

The latter part of my paper sums up the whole subject as I see it. There is no doubt that the military authorities would prefer a commercial engine if they can get it. If commercial engines are not available, it is essential that the Ordnance Department go in for development. It must have engines suitable for its purposes. The military people might modify their ideas somewhat and some of the manufacturers might modify the structure of the production somewhat, in this way making commercial product for military use an accomplished fact. It is a tremendous task to put anything new into production on short notice, even though there is an unlimited amount of money and effort available. So the Army must have a suitable and preferably a consistent line of designs of engine. The same thing holds true in the case of the complete vehicles. The question is how to bring this about. No mechanism as complicated as motorized equipment can be developed and put into production quickly.

PRESIDENT J. G. VINCENT:—In connection with aircraft and motor-truck problems, everything these officers have

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said about the possibilities of getting proper engines quickly applies equally and more forcefully to them.

Many of the Air Service officers feel that to be sure of obtaining engines in a time of stress they must commercialize aviation. In some way, engineers must also be developed so that they will be in existence when the call comes for them.

E. A. JOHNSTON:—During the preparations for war, I was called upon to look over many specifications covering tanks and other automotive war equipment. While the company I represented was willing and anxious to undertake all of this war work which it could handle, we were unable to make satisfactory progress because the designs were radically different in many respects from our standard product. It will be difficult to obtain the best possible results if it shall be necessary to depend upon commercial engine designs for war equipment, on account of special requirements.

I believe that tractors developed for agricultural purposes will prove unsatisfactory for war purposes, and vice versa. The automotive industry has great numbers of standard machine tools of all descriptions, but a limited capacity for producing patterns, dies, jigs, tools and fixtures. Consequently, if the War Department could design special equipment to meet its conditions and would also design jig, die, tool and pattern equipment, keeping this equipment up-to-date, it would be a comparatively simple matter for the automotive industry to get into production in a comparatively short time.

A. B. BROWNE:—Experience with the procurement division of the Army demonstrated that vehicles built to Government standards were really the easiest of production, after the period necessary for tooling-up had passed. Although the standardization program advocated at the beginning of hostilities was afterwards abandoned in part for the utilization of existing types of vehicles, this was very largely due to the fact that the demands of the Army were such that the requisite period of tooling-up for production, and the equally necessary period of testing, could not be permitted. As an alternative, selections were made from among the better type of commercial trucks and such slight modifications were made as were necessary to adapt them to Army use. It is to the credit of the manufacturers that they willingly supplied their working drawings of these trucks for use by separate sources of supply, and thereafter as

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little difficulty was experienced in obtaining the necessary production as was the case with the Army standardized vehicles. At one period, it seemed that it was about to become necessary to take over all the available truck-producing capacity of this country. A serious drawback to this program was encountered, however, in the fact that assemblers of many different vehicles used the same units in their construction; hence production was seriously limited by the capacity of the various parts makers.

In considering a future program, it should be borne in mind that, when an emergency arises, there is no time in which to develop new models. From five to seven months is necessary to tool-up for a new-model truck, and few manufacturers would have the temerity to place a new model on the market without having road-tested it for from six months to a year. It would seem, therefore, very necessary for the Army to accommodate itself to existing models. Whether these models should be strictly of Army design, or selected from existing commercial designs, is a question for serious thought. Improvement in automotive engineering is so rapid that Government standards would have to undergo continual change to keep abreast of the times. Commercial standards, on the other hand, are kept continually up-to-date, but it should not be forgotten that advancement in design, like any other change, continually renders obsolete many stock parts. Hence, in view of all conditions, it would seem desirable for the Army to maintain as small an equipment of trucks and other automotive apparatus as is consistent with actual necessity, and that a trained engineering staff in each branch of the Army keep continually in touch with the latest developments, so that production might be concentrated on the fewest possible number of types in case of emergency. While it is true that an equal length of time would be required for a second source of supply to tool-up for the manufacture of an existing commercial type, the test period would be obviated and the Army would have immediate advantage of the existing production which, from the fact that it did represent the latest development, would undoubtedly already be of large capacity. This country has demonstrated its wonderful production capacity, and it is in my opinion safe to depend upon this resource with the utmost confidence.

The statement that it is the desire of the Army to

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keep civilian engineers in close touch with its conditions is most commendable. In the recent war, the most serious handicap imposed upon the automotive engineers was their unfamiliarity with military requirements. They knew the job fairly well, but did not know what the Army needed. If this information was available, it was not placed in possession of those who were engaged in the procurement of automotive material until well into the year 1918. Once known, its effects were immediate, and from June 1 until Nov. 11, 1918, the production of trucks for Government use exceeded the former maximum output by over 400 per cent.

W. S. NATHAN:—I am interested in the engine requirements of the Ordnance Department, especially in the 400-hp. unit. Has the idea of multi-engine equipment been considered? Would it be advisable to take, say, 45 or 60-hp. engines of commercial make and incorporate them in a standard design of tractor; in that way securing reliability and the advantage of being able to utilize commercial equipment?

COLONEL RUGGLES:—One difficulty of having the Government adopt a special design of engine and then make jigs and tools for it is the numbers of jigs and tools we have to have ready. Another very important factor is the keeping of the engine, jigs and tools up-to-date. I believe we cannot persuade Congress to permit us to make jigs and tools every two years. Congressmen would want to know where the old jigs and tools were and why they would not serve. We would be hopelessly behind the times.

We must adopt some engine that is of a commercial type or get the commercial firms to adopt our engine and keep it up-to-date. Enough has been said in the various discussions to indicate what a tremendous problem industrial preparedness is. It is too much for a handful of officers. It is not a problem for military people only; it is the problem of every American citizen. Unfortunately, many people in this country think that if we have men we have an army. That is a mistake. The men are born at least eighteen or twenty years before a war, but the munitions have to be born at the time of the war, because, unfortunately, our country will not consent to carry on hand a large supply of munitions. The best we can hope to do is to have our designs perfected, our plans well thought out, our factories prepared and our engineers trained, so that we can get into war production at

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the earliest possible moment after the emergency develops.

The problem is too great for the Ordnance Department alone. We hope to present all the problems so that the whole Society will know just what the difficulty is and what progress is being made. It is a question of educating the people to act through Congress to keep the country prepared.

DECREASING UNSPRUNG WEIGHT BY THE USE OF ALUMINUM

By A H Edgerton[1]

Stating the desirability of reducing unsprung weight in motor vehicles as a recognized fact and that 75 of 100 engineers interviewed favor such reduction, the particular advantages resulting are given as improved riding qualities, economy in tire wear and better acceleration. Mathematical deductions to establish the most desirable ratio of sprung to unsprung weight are not attempted, the intention being rather to state the reasons favoring lighter wheels and axles.

Unsprung weight effects depend primarily upon the ratio of sprung to unsprung weight. No data determining the most desirable ratio are available, but an investigation of the proportional weight of the unsprung and sprung parts of good-riding-quality automobiles showed it to be about 1 to 3. By constructing the wheels and the axles of light metal it is possible to maintain such a ratio, assure good riding qualities and reduce the total weight.

Laboratory and road tests prove that more mileage can be obtained from a light than from a heavy wheel. A comparative test was made between an aluminum and a steel wheel mounted at opposite ends of the same rear axle of a truck, each equipped with a 36 x 6-in. tire. Running on the surface of a drum having cleats to cause shock, the tires and wheels were subjected to a total of 6,009,300 impacts. The steel-wheel tire showed deep cracks, but that on the aluminum wheel only small fractures; there was no trace of any metal fatigue.

By decreasing the wheel and axle weight, the inertia that must be overcome in accelerating is reduced pro-

[1]Aluminum Manufactures, Inc., Cleveland, Ohio.

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portionately. In the test described, the moment of inertia of the aluminum wheel was 53 and that of the steel wheel 123. The force needed to produce a given angular velocity of the wheels in a given time is directly proportional to the moments of inertia of the wheels. It follows that an aluminum wheel consumes less power in attaining its angular velocity than a wheel of the same mass distribution but of greater weight.

The desirability of reducing the unsprung weight in motor vehicles is a recognized fact. Statistics recently gathered indicate that 75 of 100 engineers interviewed on this subject favor the reduction of unsprung weight, 15 expressed themselves as not knowing, while the remaining 10 per cent would not commit themselves. With so great a proportion favoring the reduction of unsprung weight we may ask what are the particular advantages to be secured? We find that the most important ones are improved riding qualities, economy in tire wear and better acceleration. No attempt will be made in this paper to present mathematical deductions which establish the most desirable ratio of sprung to unsprung weight. The intention is rather to introduce a few arguments in favor of lighter wheels and axles.

Improved Riding Qualities

An automobile body virtually floating in space and insulated from the vibratory action set up by the road irregularities would be ideal. The less the unsprung weight, the less the energy to be absorbed by the springs for a given road shock and the less the spring flexure. An ideal spring would have such resilient qualities that it would absorb and respond to the slightest shocks and at the same time possess such strength and have so wide a range of movement that it would absorb the maximum shocks. Numerous spring types have been offered as the solution of the spring-suspension problem, but with every type the fact is recognized that the effects of the unsprung weight depend primarily upon the ratio of sprung to unsprung weight.

There are, to my knowledge, no data that determine the most desirable ratio of sprung to unsprung weight. An investigation, however, of the proportional weight of the unsprung and sprung parts of cars generally considered as possessing good riding qualities show that the ratio is about 1 to 3. On a car weighing 2600 lb. and with a

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1 to 3 ratio, the unsprung weight would be 650 lb. If the total weight of the car is reduced to 2000 lb. and the same ratio maintained, the unsprung weight would be 500 lb. It is safe to assume that the weight of the lightest wheel in general use, including its tire equipment, is 75 lb., or 300 lb. for the four wheels. In a car weighing 2000 lb. and having the ratio of unsprung to sprung weight mentioned, only 200 lb. of material can be used in the axles. It is impossible to make two axles weighing only 200 lb. out of any material now on the market other than aluminum for a car weighing 2600 lb. If a lighter material is used in the construction of the wheels, a more liberal weight will be allowed for the axles and their parts. By constructing both the wheels and the axles of light metal, it is within the range of possibility to maintain the ratio mentioned, assure the desired riding qualities of the car and at the same time reduce the total weight to 2000 lb.

It has been shown by mathematical calculations that it is possible to improve the riding qualities of a car by reducing the unsprung weight. The body or load of a vehicle can be suspended to advantage when the wheel is kept in contact with the ground. The higher the ratio of sprung to unsprung weight and the lighter the wheel, the better the riding qualities of the car become. To attain ideal riding qualities the springs should be designed to afford sufficient amplitude of deflection to cause the wheels to follow the contour of the road irregularities. This can only be obtained in theory by infinitely flexible springs, but in practice the flexibility of the spring motion must be restricted so that the spring may perform its functions without necessitating too much clearance between the spring and the frame. For a given suspension range the best spring is that which has the slowest periodicity, this depending upon the difference between the unloaded and loaded camber of the spring.

As we increase the speed of an empty truck, we find that road adherence becomes unfavorable and that shocks and vibrations of such empty trucks cause rapid deterioration. These shocks and vibrations frequently are responsible for the loss of time for examination and repairs to the parts. For trucks employed in rural transportation work, where heavy loads at high speeds are required, there is no better way to prevent the rapid deterioration of the engine than to safeguard it by attaining better riding qualities.

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If we consider the total sprung weight of a truck as a mass which must be held in balance, we must find a value for the unsprung weight that will allow the springs to absorb the normal vibrations and hold the body in a perfect poise. If the designer establishes the weight required in the body to keep the wheels in contact with the road, the springs will tend to function as a means of keeping the wheel in constant contact with the road in the same way that a valve-spring keeps the valve follower in contact with the cam. There is no doubt that the day will come when automotive engineers will establish the best ratio of sprung to unsprung weight, and that they will then specify the weight of the wheel and the axle for any particular truck.

One of the recent interesting developments pertinent to the reduction of unsprung weight is that of the aluminum truck wheel. Both disk and spoke-type wheels have been built which are from 50 to 60 per cent lighter than wood or steel wheels. Extensive road and laboratory tests indicate that the new wheel possesses all the desirable features claimed for the wood or steel wheel and in addition embodies certain very important advantages not possessed by either of the existing types. A reduction of 50 per cent in weight was made in one case of an aluminum wheel for use on the front axle of a 3-ton truck as compared with a wood wheel and the lightest steel that could be found for the same service. Another interesting reduction in weight was found in a rear-axle housing that was redesigned for the use of aluminum and in which a saving of 38 per cent was attained without sacrificing the strength of the axle in any way.

Economy in Tire Wear

It has been proved that more mileage can be obtained from a light wheel than from a heavy one. This statement is supported by both laboratory and road tests. The road test covers a period of 4 years. The comparison was made on two trucks of the same model and design both operating under similar conditions. One truck was equipped with extremely light wheels; the other, with heavy wood wheels. The latter were of a conventional design and the standard equipment for the truck. During this period of 4 years three sets of tires were completely worn out on the truck with the heavy wheels, but the one with the lighter wheels is still runing on its second

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set of tires, and judging from the last report the tires are good for a great many more miles.

The laboratory test was conducted to determine what effect a high vibrating action or constant pound would have upon the tire and the wheel. An aluminum wheel weighing 82 lb. equipped with a 36 by 6-in. tire was mounted on one end of the rear axle of a truck. On the other side of the truck a steel wheel with similar tire equipment weighing 248 lb. was mounted. The truck was then set up on a test stand which brought the wheels in contact with a large cast-iron drum 16 ft. in circumference. Cleats ¾ in. high, and spaced about 4 ft. apart, were bolted across the face of this drum. The truck was secured with chains and staybolts against forward and lateral movements and, as the drum was free to rotate, it was possible to drive the truck under its own power and at a speed to attain a very severe pound on the wheel and tire. A run of 500 miles was made at a speed of 15 m.p.h. At the conclusion of this test it was found that the tire on the steel wheel showed deep cracks across the face. These cracks were 6 to 8 in. apart and in one instance the fracture penetrated the entire depth of the tire. The tire on the aluminum wheel had small fractures around both outer edges or corners of the tire. These were about ¾ in. wide and 2 in. long, but the central portion of the tire remained as good and as solid as at the beginning of the test. The tires and wheels were subjected to 19,800 impacts per wheel per hour, or a total of 6,009,300 impacts for the whole test. It should be added here that the truck was loaded to its capacity during the test.

At the conclusion of the test a careful examination of the wheels revealed no signs of fracture or metal fatigue of any kind. An additional advantage of the aluminum wheel is the ease of tire removal where pneumatic tires are used. Aluminum will not rust and, as the aluminum wheel has a rim and side-ring of the same material, the tire will not "freeze." Everyone is familiar with the difficulties encountered in removing a tire that has been on an ordinary wheel for a long time. This operation is both tedious and troublesome, particularly when a tire change is necessary on the road. A tire engineer of one of the largest companies recently stated that this was one of the greatest difficulties the tire manufacturers had to face. While galvanizing has been offered as a solution of this problem, it is conceded that this is by no means entirely satisfactory.

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Better Acceleration

In all the larger cities traffic in certain districts is so congested that a driver has to make innumerable stops, sometimes several in a single block. It is believed that in considering the acceleration of a vehicle, the point of most general interest centers in that phase of the problem which deals with the momentum of the car or truck when starting from rest.

Considerable effort has been expended in an endeavor to better the "get-away" of cars, though it appears that little attention has been given to one of the salient factors, that of reducing the weight of the wheels and the axles. By decreasing such weight we reduce proportionately the inertia that must be overcome in accelerating.

Experiments have consequently been made to determine the moments of inertia of a light and of a heavy wheel. An aluminum and a steel wheel were chosen, each being designed for a 3-ton White truck equipped with 38 by 7-in. pneumatic tires. The aluminum wheel weighed 62 lb. and the steel one 149 lb. A clamping device was made so that the wheel could be gripped at the outer edges of the rim. A bar which was secured to the clamp in a position parallel to the hub axis of the wheel supported the wheel as a pendulum and was mounted on knife-edges so that the wheel was free to swing from this suspension point.

With the wheel thus suspended we are able to find the time per oscillation in seconds and the moment of inertia can then be obtained by the formula

$$I = \frac{mrgt^2}{\pi^2} = \frac{wrgt^2}{g\pi^2}, \text{ where}$$

I = the moment of inertia in inch units

m = the mass or $\frac{w}{g}$

r = the radius of the wheel in inches
g = the force of gravity or 32.2×12
t = the time in seconds for a single oscillation

It was found that the moment of inertia of the aluminum wheel was 53 and that of the steel wheel 123.

For any power-driven vehicle the force needed to produce a given angular velocity of the wheels in a given

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length of time is directly proportional to the moments of inertia of the wheels. From this it follows that an aluminum wheel consumes less power in attaining its angular velocity than a wheel of the same mass distribution but of greater weight.

The ratio of the energy of forward motion to the energy of forward motion plus rotation for a wheel is as 1 to 2. With a pneumatic-tired wheel having an outside diameter of 38 in., it is obvious how exceedingly important it is that rim weight should be kept as low as possible, particularly on low-gear cars and trucks where the rim inertia forces are a large proportion of the whole inertia of the vehicle. When a car is accelerating, say from rest to 20 m.p.h., the wheels have to be accelerated from rest to 40 m.p.h.

An interesting phase of the advantage incident to a reduction of the unsprung weight of a truck is illustrated by the following example. A certain 2-ton truck, highly efficient in its performance and of recognized merit, has a total unsprung weight of about 2600 lb. and a sprung weight of 4900 lb. We may assume that the engineer who designed this truck considered a ratio of unsprung to sprung weight of 1 to 1.8 as giving a proper distribution of weight and that this ratio was ample for the class of work expected of the truck. By substituting lighter wheels and introducing lighter metal in the axle parts, a saving of 658 lb. in the wheels and 160 lb. in the axles was obtained. This reduced the unsprung weight to 1800 lb. Using the ratio just mentioned, 1 to 1.8, we can maintain the same proportional weight distribution if we have a sprung weight of 3400 lb. The total weight of the truck with the heavy wheels and axle when loaded to capacity was 11,500 lb., while a total loaded weight of the lighter truck would be 9200 lb. Computing the energy necessary to accelerate the truck from rest to 10 m.p.h., we find that the truck equipped with the lighter wheels and axles showed a saving of 20 per cent over the one with the heavier wheel installation.

A further slight conservation of energy may also be considered due to the reduced tire friction, and it is quite obvious that a considerable tire economy will be realized when the total truck weight is reduced. It should further be noted that a truck designed to the lighter figures mentioned, in which a reduction of 20 per cent in the power necessary for acceleration is attained, should show a materially better fuel economy.

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THE DISCUSSION

A. Y. DODGE:—It was mentioned that 500 lb. of wheel weight was saved. On what size of truck can this saving in weight be made? What is the size of the truck upon which the dynamometer tests were made?

A. H. EDGERTON:—The truck on the dynamometer stand was a 2-ton truck loaded to capacity. The aluminum wheel weighed 82 lb. and the steel wheel 248 lb. The comparison was consistent, as there was no tire on either wheel.

F. D. HOWE:—Is there a definite figure for the ton-mileage obtainable from a set of tires on the lighter aluminum wheels, as compared with that obtainable with the heavier steel, or wood, wheels? The wheels will cost more. Will this additional cost be compensated for by greater tire mileage?

MR. EDGERTON:—I have not investigated that phase as yet. The wheel has been in an experimental stage; we have had many problems and have never made any comparisons. The information is I think easily obtainable by calculation or by comparison.

A. E. WINKLER:—How does the advantage gained by the application of aluminum wheels to trucks compare with that gained by their application to passenger cars?

MR. EDGERTON:—We have built a passenger-car wheel that differs greatly from the orthodox wheel, the difference being in the construction of both the rim and the face of the wheel. It has the tire seated directly on the aluminum and the face is entirely unmarked by bolts or rivets. There is an advantage in weight of 7 lb. over the wire wheel and as much as 40 lb. over the steel wheel.

MR. WINKLER:—How were those wheels attached?

MR. EDGERTON:—They were detachable wheels.

A. B. BROWNE:—Have any actual tests been made of the aluminum wheels both before and after they have been in service?

MR. EDGERTON:—Our first action was to test the wheels before they went into service. We have a set of wheels which have been run several years; we expect to test them but have not as yet done so. It appears to me a waste of time. The wheels are apparently in as good a condition as they ever were. We have inspected them and hammer-tested them for cracks. I cannot believe that there would be any advantage in making a test after the wheel was run; however, we expect to make it.

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JOHN MCGEORGE:—Has any test been made to determine whether the elastic limit has been exceeded, due to so-called crystallization?

MR. EDGERTON:—We have run the wheel under the vibratory action already described. We did not run it to destruction or to obtain a crystallization. A test of that sort would require much time, because this alloy has sufficient elongation to cause it to bend considerably before it breaks and I believe the wheel would not crystallize.

W. S. NATHAN:—Are these wheels die-cast or sand-cast? What parts are finished?

MR. EDGERTON:—All wheels have so far been sand-cast. They are machined only on the parts subject to mounting, such as the tire seat, bearings and hubs, and such drilling as is required. The outside face of disk wheels for passenger cars is machined; otherwise, disk wheels are not faced.

B. M. IKERT:—What are the relative advantages of the spoke type of wheel and the disk type?

PRESIDENT J. G. VINCENT:—If one or the other has an advantage, has any difficulty in casting been found? Are there the same shrinkage strains that occur in steel or malleable wheels?

MR. EDGERTON:—We have made both spoke and disk wheels. There is very little difference as far as the foundry work is concerned. The hollow spoke on the spoke-type wheel requires slightly more core work, but the wheel has been equally successful in both types, finally. All tests indicate no advantages favoring one type over the other. The weight saving and the strength appear about equal in either case.

F. J. BEDFORD:—What is the effect on the traction balance due to lightening the unsprung weight? The point was made whether the traction would be as good with the lighter unsprung weight as with the truck as originally balanced, particularly with varying loads.

MR. EDGERTON:—We have made it a point to watch for any effect that might occur from that, but there has never been any noticeable result. With the truck loaded the wheels maintain the proper traction and do not slip; the light wheels do not spin more than heavy ones, nor are the tractive efforts unbalanced.

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DESIGN OF PNEUMATIC-TIRED TRUCKS

By C M McCreery[1]

After stressing the importance of transportation, the possible uses of the motor truck are considered. The increased cushioning and traction obtained from pneumatic truck tires accomplish faster transportation, economy of operation, less depreciation of fragile load, easier riding, less depreciation of roads and lighter-weight trucks. These six advantages are then discussed separately and various data to substantiate the claims made are presented. Following detailed consideration of transportation and operation economies, and depreciation of loads and roads, the practicability of pneumatic tires is elaborated, and wheels, rims and tire-accessory questions are studied.

The four main factors bearing upon truck design for pneumatic tires are stated and discussed; emergency equipment for tire repair is outlined and a new six-wheel pneumatic-tired truck is described. Five primary changes from present solid-tire design are necessary in the design of the ultimate truck to use pneumatic tires; these are stated in the summary.

The truck designers are just now on the first flood of expansion in the world's next advance in transportation, but before discussing specifically the subject of this paper I would like briefly to point out how forms of transportation have extended civilization by broadening education and developing natural resources.

Going over the history of the rise of all nations briefly as a corollary to the transportation systems of those nations, we first know of little groups of barbaric individuals going about on foot; then of transportation by domestic animals, bringing forward Egypt, followed by Babylonia and Persia; then of Greece forging to the fore through transportation by hand-propelled boats. Larger boats pronounced Rome the leader and Rome also assured its permanent prominence by building good inland roads, making transportation by domestic animals faster and more efficient. Then followed sailing ships and we hear of Genoa and of Venice. Transportation over the ocean brought Spain and England to the front as leading world powers, and so they remained until the

[1] Highway transportation division, development department, Goodyear Tire & Rubber Co., Akron, Ohio.

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advent of the steam engine early in the nineteenth century.

Countries like America and Germany, with large areas of internal territory to develop, then began to assume the leadership and this was the status of affairs until our own day when the development of the internal-combustion engine and the pneumatic tire made possible the automobile, now an important form of transportation which will in the future take a more and more prominent place than any former means of transportation. What part the automobile plays from now on must affect vitally the civilization, progress and development of the whole world and its people, and how great its effect will be rests with you members of the Society of Automotive Engineers.

Possible Use of the Motor Truck

The field of motor transportation is beyond human comprehension. With billions of people to be transported every hour in the day and also with millions of tons of freight to be moved, the conveyance which completes the delivery with the least loss of time must predominate. Time is a factor of greater value than money, although we are all prone to determine costs by dollars rather than by the clock. So it is your task to produce motor trucks that will dominate as the world's greatest medium of transportation. It is our claim that the pneumatic tire, when its advantages are known and used to the fullest extent possible in truck design, makes possible this hope of future domination of the world's transportation by the motor truck.

Your past experience recalls the bicycle with first a steel, then a solid and then a pneumatic tire. People said the pneumatic tire would not do because it punctured, which was true; and that it cost more, which was true; but the bicycle did not continue on solid tires because the pneumatic tire gave it a wider field of usefulness. The rubber-tired carriage followed much in the same manner, except that the combination of the gas engine and pneumatic tire practically eliminated the horse from passenger transportation and bids fair to succeed the electric street car in that respect. Today there are more passengers per mile carried by automobile than by any form of rail or water transportation. But the carriage and transportation of merchandise has not developed as rapidly as has the transportation of passengers.

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While motor trucks have already played an important part in world conditions, they have done so largely as auxiliaries to existing means of transportation. This we sincerely believe to be due to the continued use of solid tires and to the design of vehicles based on the use of solid truck tires. The lack of development of a suitable pneumatic truck tire by the tire designers is the most plausible reason for this condition, but during the past few years our development and research work have proved that pneumatic tires for trucks have been perfected to a point sufficient to justify a belief upon the part of the most conservative engineer that the pneumatic must be the ultimate tire for trucks in both passenger and freight transportation. Trucks designed to take the fullest advantage of the use of pneumatic tires can and will dominate the transportation of the world.

Most of you, I think, believe in the pneumatic tire principle for motor trucks, but are you convinced that they are practical and economical? To prove that they are one has but to search the records of experience of users. Any discussion of the relative merits of pneumatic versus solid tires must, of necessity, reduce itself to a comparison of the elasticity of compressed air with that of rubber. We all are accustomed to think of rubber as a very elastic substance, but it cannot be compared to compressed air in this respect. In one instance you ride on rubber; in the other, on air. Very little stretch of imagination is necessary to realize what would happen to a modern passenger car if it were to be equipped with solid tires. The reasons that motor trucks can be operated with any degree of success on solid tires are, that they are operated at relatively low speeds and are built very heavy so that they will endure the shocks and vibration to which they are subjected. If it is possible to use pneumatic tires on passenger cars to such advantage, it is reasonable to assume that certain advantages will result from their use on motor trucks.

It has been found that there are two fundamental advantages which result from the use of pneumatic truck tires: (*a*) increased cushioning, and (*b*) increased traction. The increased cushioning is the most important factor because it has a greater effect on the performance of the truck. Elsewhere I will show that the cushioning ability of a pneumatic tire is four times as great as that of a solid tire of the same carrying capacity. As a result of this greatly increased cushioning there are six dis-

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tinct advantages gained from the use of pneumatic truck tires:

(1) Faster transportation
(2) Economy of operation
(3) Less depreciation of fragile load
(4) Easier riding
(5) Less depreciation of roads
(6) Lighter-weight trucks

Each of these six points will now be discussed separately and, wherever possible, actual data will be presented to substantiate the claims made. The data have been obtained from truck operators, each of whom has taken two trucks of the same make and capacity, one equipped with pneumatic and the other with solid tires, and operated them under exactly similar conditions, over the same roads and carrying similar loads.

Transportation and Operation Economies

Faster transportation or quicker deliveries result from the increased cushioning of pneumatic truck tires. Operators have found this to be true because it is possible to obtain greater maximum and minimum speeds. Manufacturers of solid-tired trucks remove their guarantee if a speed of 11 or 12 m.p.h. is exceeded, while pneumatic-tired trucks are being successfully operated at 20 to 35 m.p.h. In ordinary city or farm hauling, however, we are more interested in a greater minimum speed than we are in a greater maximum. That is, in running over rough city streets or country roads, a solid-tired truck must operate at slow speeds because of the shock and vibration. It is therefore evident that if a truck on pneumatic tires will make more or longer deliveries in a given number of hours, its radius of operation is increased and also its earning power. Table 1 will show the increased mileage obtained with pneumatic tires by four truck operators.

TABLE 1

Operator	Truck Capacity, tons	Period, months	Mileage on Pneumatic Tires	Mileage on Solid Tires
A	2	6	6,414	4,476
B	3½	1	1,995	675
C	2	5	5,510	2,223
D	2	4	7,014	4,677

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The economy of operating trucks on pneumatic tires has been shown by the experience of many users. There is a considerable saving in gasoline, oil and upkeep. Furthermore, depreciation charges can be reduced considerably. The saving in gasoline is due to a lower power consumption resulting from the increased cushioning obtained. It is a well-known fact that vibration in a machine of any kind results in a loss of power. The vibration caused by the solid tires is practically eliminated by the use of pneumatic tires. A solid tire, in rolling over an obstruction in the road, lifts the entire load on the tire four times as high as it would be lifted in the case of a pneumatic tire. Many roads are full of small obstructions so that a certain amount of power is lost in lifting the load of the truck over them. The relative cushioning ability of the two types of tire seems to indicate that the power loss from this cause is four times as much for solid as for the pneumatic type. There is also a saving in power in climbing hills. Because it is possible on pneumatic tires to approach a grade at a much higher rate of speed, less power will be consumed in climbing the grade; it will not be necessary to shift gears as soon, and possibly not at all. The saving in gasoline in the case of five truck operators is shown in Table 2.

TABLE 2

Operator	Truck Capacity, tons	Period, months	Miles per Gallon of Fuel	
			Pneumatic Tires	Solid Tires
A	2	6	5.77	3.98
B	3½	1	5.75	4.77
C	2	5	7.21	5.43
D	2	4	7.70	7.10
E	2	9	9.10	6.10

The saving in oil is probably due to the decreased vibration in all of the moving parts of the truck. The statistics from four truck operators, given in Table 3, show that there is a considerable saving in oil consumption.

The upkeep or repair cost of a truck operated on pneumatic is much less than when operated on solid tires. This can be attributed to the decreased amount of vibration and the absence of severe shocks and jolts. It is found that parts do not have to be replaced and that the

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truck does not need to be overhauled as often. Reliable information has not been obtained, but the estimated saving in upkeep cost is from 25 to 50 per cent. There is also the subject of depreciation charges. As a result of experience our solid-tired trucks are depreciated on the basis of 60,000 miles of service, while the pneumatic-tired trucks are depreciated on a basis of 80,000 miles. It seems that 80,000 miles is too low, because there have been trucks on pneumatic tires which at the end of 250,000 miles were still in running condition. I believe that in the near future trucks will be depreciated on the basis of 100,000 miles. Taking all of these cost factors into consideration, it is found that the cost per mile of operating trucks on pneumatic tires is considerably less than that on solid tires. Referring again to the data obtained from truck operators who have kept accurate records, this claim is substantiated. (See Table 3.)

Depreciation of Loads and Roads

Let us now consider the lessened depreciation of fragile loads resulting from the increased cushioning ability of pneumatic truck tires. This is considered by many users to be one of the most important advantages. For instance, in hauling fragile materials, such as bottled goods and eggs, there is very little, if any, breakage. The farmer experiences very little depreciation in the live stock and produce which he hauls to the markets.

There is also the easier riding made possible by the use of pneumatic tires. In the case of delivery trucks, the elimination of the vibration makes it possible for the truck driver and his helper to ride almost continually

TABLE 3

Operator	Truck Capacity, Tons	Period, Months	Miles per Gallon of Oil: Pneumatic Tires	Miles per Gallon of Oil: Solid Tires	Cost per Mile in Cents: Pneumatic Tires	Cost per Mile in Cents: Solid Tires
A	2	6	104.0	59.0	45.0	56.3
B	3½	1	32.0	30.7	31.3	55.0
C	2	5	55.0	54.0	21.5	24.0
D	2	4	152.0	78.0	27.7	31.0

without fatigue. This is of vital importance, especially in long-distance hauling where it is necessary to drive for hours at a time. Easy riding is absolutely essential in passenger buses from the standpoints of comfort and speed.

Before the motor truck can be utilized to the full extent

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of its possibilities, good roads are essential. However, along with the legislation providing these, laws are being considered and in some instances passed restricting motor-truck traffic. A pneumatic-tired truck has very little more harmful effect on an improved road than a passenger car. This is not true of a solid-tired truck. Because of the vibration and sharp jolts common to solid tires, any road will eventually break down under such traffic. The effect on dirt roads is the most harmful. The narrow, hard tread of the solid tire will soon cut into the road, whereas the soft, wide tread of a pneumatic tire will not. Attempts have even been made to prohibit solid-tired trucks from using certain roads, and on some of the principal thoroughfares of our cities this has already been done. In such cases pneumatic truck tires have a distinct advantage.

The discussion so far has considered only increased cushioning. The advantages of increased traction will now be stated. Increased traction is made possible by the greater width of the pneumatic tires, their non-skid treads and their greater flexibility, which allows the surface of the tire to conform more nearly to the unevenness of the road, thereby getting a better grip. There is nearly twice the area of ground contact with pneumatic than there is with solid tires of similar capacity. As a result of this increased traction, we obtain reliability and safety. By reliability, we mean that it is possible for the truck to operate successfully over almost any kind or condition of road, and during all seasons of the year. By safety, it is meant that because of the increased traction of the tires, the truck will hold the road better and the brakes will be more effective.

We have so far discussed only the advantages of using pneumatic tires on trucks. I think it is advisable to mention some of the arguments which have been advanced against the use of pneumatics and truthfully answer them as experience has shown that they can be answered. All of the arguments against the use of pneumatic tires can be placed under either of the following: (*a*) cost and (*b*) practicability. The question of cost will be discussed first. It is now found that the matter of cost is subdivided into two parts: (*a*) initial cost, and (*b*) the possible loss due to injury and abuse. While it is true that the initial cost of pneumatic-tire truck equipment is greater than that of solid-tire equipment, it has been proved by the experience of many truck operators that

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this difference is more than offset by the greater earning power and the lower cost of operation. It has usually been found that in 4 to 6 months' time the increased cost of the pneumatic-tire equipment is completely wiped out. When the time comes that specially designed pneumatic-tired trucks make their appearance, this increased cost will be offset by the lower initial cost of the truck itself, and the greater economy of operation.

As to possible loss due to injury or abuse of the tires, it has been found that this is not a serious objection. There are innumerable instances where pneumatic truck tires have run from 12,000 to 20,000 miles on the original air. As the development of the tires themselves has progressed, so has the successful repairing of the tires been worked out. Repair molds and retreading equipment are now in use in many parts of the country and are being placed in other localities as rapidly as possible, so that it will be no more difficult to have a pneumatic truck tire repaired than any other part of the truck. While it is possible to injure pneumatic truck tires by abuse, this is no more likely to happen to the tires than to other parts of the truck, and it is possible to repair most of the injuries that tires receive from abuse. As truck operators become more accustomed to the use of pneumatic tires, such failures will be reduced.

Practicability of Pneumatic Tires

The practicability of pneumatic truck tires has probably been questioned more than has any other feature. The first thing to be discussed under this subject is that of delays due to changing tires. The amount of time necessary to change a tire depends in part upon the type of rim equipment. In the case of detachable rims, where it is necessary to remove the tire from the rim, replace it and then inflate it, not more than 30 min. is required to perform the entire operation. In the case of a demountable rim, a change can easily be made in 15 min. I am not trying to argue the relative merits of the two different types of rims, but is an occasional delay of from 15 to 30 min. to be considered when we know that we can save hours, not minutes, every day that the truck is in operation when it is equipped with pneumatic tires? The truck driver is not required to make a tire change very often.

It is often said that it is not possible to maintain the high inflation pressure required for pneumatic truck

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tires. Very little difficulty has been experienced in this respect. Most garages and service stations carry sufficient air pressure to inflate tires up to 42 by 9-in. size, and many are preparing to take care of the largest sizes. By the time the largest tires are in general use there will be generally available air at a sufficient pressure to keep them properly inflated. Trucks equipped with detachable rims, or operating in long-distance or inter-city service, are usually equipped with small air compressors. One objection which is not mentioned so much now as when pneumatic truck tires first made their appearance, is the danger of the high inflation pressures. Pneumatic tires are made to withstand three to four times the pressure carried in them.

The large outside diameters of the tires are often objected to because they affect the truck ability and because they raise the center of gravity. In changing over a solid-tired truck to pneumatics, there is the possibility of reducing the ability of the truck. Our experience has shown that unless the truck is operated over a very hilly route, its ability has not been noticeably affected. There have been too many successful change-overs to allow this to become a serious objection. Looking into the future, this question of truck ability and gear ratios will be taken care of by changes in design. So the question of change-overs is only temporary. Raising the center of gravity is not as serious as it might seem. The question of getting the load into the truck has not been a serious question at all. I do not believe that the loading platforms are of such uniform height that a little change in the height of the truck platform would make a great difference.

I have heard it said at different times that in case of a large rear tire suddenly going flat, the sudden drop of the truck might turn it over on a crowned road. When a big tire goes flat, it does not do so suddenly. The blow-out or cut in the tire is never very large, so that it takes some time for the air to escape. Therefore, the truck does not tip suddenly. Furthermore, when all of the air is out of a 48 by 12-in. tire, the largest now made, there is a drop of only 5 in. Now assume that the tread of the rear wheel is 66 in., the list of the truck would be approximately 4½ deg., which is not enough to cause the truck to turn over, and to my knowledge no truck has ever overturned from this cause. The sizes that have been worked out during the past 6 years are now stand-

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ard. Table 4 gives the rim sizes, normal tire sizes and the tires which can be fitted as oversizes.

TABLE 4

Rim Sizes, in.	Normal Tire for Rim, in. (Original equipment on new trucks)	Oversize Tire for Rim, in. (Intended for convenience of consumer and not for original equipment)
34x 5	34x 5	36x6
36x 6	36x 6	38x7
38x 7	38x 7	40x8
40x 8	40x 8	42x9
[2]40x 8	42x 9	
[2]44x10	[2]44x10	
[2]48x12	[2]48x12	

[2]These sizes are not S. A. E. tire and rim sizes.

You will notice from this table that there is no oversize possibility when 9, 10 and 12-in. sizes go out on new trucks because the oversizing plan falls down above the 9-in. size, on account of the size and stiffness we are forced to build into the beads as designed at present.

I would like to discuss the questions regarding loads and inflations at considerable length but can only do so briefly and tell something of what pneumatic tires can stand in the way of flexing, so that the table of loads and inflations can be understood. (See Fig. 1.)

To the best of my knowledge tires give the greatest satisfaction when they have plenty of cushioning and not too much flexing. The latter condition is what breaks down a tire, when run under conditions which produce a deflection of from 12 to 15 per cent of the section diameter, or 12 to 15 per cent of the height above the rim. The deflection can be controlled by regulating either the

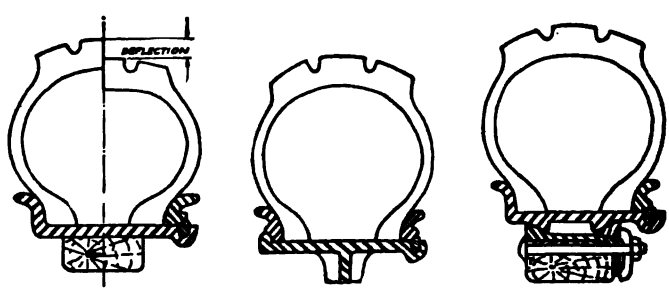

FIG. 1 FIG. 2 FIG. 3

TYPES OF PNEUMATIC TIRE IN COMMON USE

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load or the pressure, or both. Table 5 gives the standard maximum load and required inflation. The pressures are practical to maintain, the tires are built accordingly

TABLE 5

Tire Size, in.	Extreme Maximum Allowable Load per Tire, lb.	Inflation Pressure, lb. per sq. in.
34x 5	1,700	80
36x 6	2,200	90
38x 7	3,000	100
40x 8	4,000	110
42x 9	[3]5,000	[3]120
[3]44x10	[3]6,000	[3]130
[4]48x12	[4]8,500	[4]140

[3]S. A. E. Recommended Practice only.
[4]Not S. A. E. Standard as yet.

and we get satisfactory practical results in first cost and mileage delivered, if the table is followed.

I want to take this opportunity to mention under-inflation and overload. Both evils result in an excessive deflection of the tire which means that an excessive shearing action is put upon the rubber between the plies and also upon the cushion built into the tire between the tread and the plies. This in turn results in a separation of the parts and the tire is on the road to failure.

Next I will show how the loads recommended for the tires are adapted to the various sizes of trucks. The Tire and Rim Division of the S. A. E. Standards Committee investigated this, and its findings appear on page 24[5] of the Report of Divisions of Standards Committee, dated June 23, 1919. The weights of practically all makes of trucks were ascertained and plotted, and it was found that all trucks of a given capacity weighed nearly the same when under full load, and it was possible to specify what the pneumatic tire equipment should be on any truck of a certain carrying capacity. The bodies of all the trucks in question were assumed to be standard stake bodies, so, of course, heavy bodies might in some cases necessitate a revision of the committee's findings. Table 6 is similar to that submitted as general information to, but not accepted by, the Standards Committee. The changes are in the tire equipment recommended for front wheels on trucks of 1½ tons and under.

[5]This report was submitted to the Standards Committee as general information only. It was not accepted by the Society for publication in the S. A. E. Handbook.

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TABLE 6

Size of Truck, tons	Front Wheels: Maximum Weight per Wheel, lb.	Front Wheels: Pneumatic Tire Size, in.	Rear Wheels: Maximum Weight per Wheel, lb.	Rear Wheels: Pneumatic Tire Size, in.
¾	800	4, 4½ or 5	1,600	34x 5
1	1,000	4½ or 5	2,100	36x 6
1½	1,200	4½ or 5	3,000	38x 7
2	1,500	34x5	3,500	40x 8
2½	1,800	36x6	4,000	40x 8
3	2,000	36x6	5,200	44x10
3½	2,100	36x6	5,700	44x10
4	2,300	38x7	6,500	48x12
5	2,700	38x7	7,800	48x12

If you check up any make of truck loaded to its rated capacity, you will be surprised to find how closely the weights on the tires come to the figures in the table.

Wheels, Rims and Valves

There are now in satisfactory service wood wheels, 8 or 10 designs of cast-steel wheels and disc wheels. On all of these can be mounted either the so-called demountable type of rim or the so-called detachable rim. The demountable rim means one on which is carried an inflated tire. The detachable rim is perhaps a misnomer, because the rim is not detachable but the tire is removed by detaching a side ring from the rim, on which spare tires cannot be carried ready inflated. (See Figs. 2 and 3.)

The arguments for the demountable rim are the inflated spare tire and the short time required for a tire change. Against the demountable are the extra weight required, the extra cost and the possibility of mechanical troubles. The detachable rim arguments are the exact opposite. In its favor are less weight and cost and a greater freedom from mechanical troubles. Against it are the arguments of time required for a tire change and means of inflating the tire after it is changed.

Tubes for pneumatic truck tires must be designed and compounded so as to retain as much of their original strength and shape as possible, after being subjected in service to more or less heat and to continued flexing. Tubes are on a par with the casings in development and render satisfactory service even in the largest tires. (See Fig. 4.)

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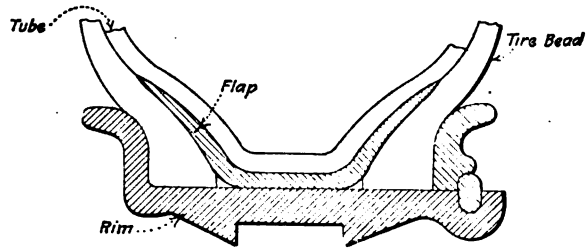

FIG. 4—POSITION OF TUBE AND FLAP IN A LARGE-SIZE PNEUMATIC TIRE

Flaps assume considerable importance in tires inflated to recommended pressures. It is important that the flap fit well so that there will be no adjustment when the tire is inflated, causing a localized stretch in the tube at the edge of the flap.

The valve question had to be approached from two angles; first, from the standpoint of holding air at pressures from 90 to 140 lb. and, second, from the standpoint of ease of tire change. The valve-insides on all tubes 6 in. and larger are of a heavy-duty type, different from the ordinary valve-insides in construction, but the two are interchangeable in any valve stem (See Fig. 5). On the 10 and 12-in. sizes, which are inflated to 130 and 140 lb. per sq. in. respectively, even the heavy-duty type is at present unsatisfactory when used alone, so a combination is used in the form of a heavy-duty valve-inside and a needle-valve operated by a hand-screw.

Another important item is the arrangement of tires on the trucks. There are three possibilities: (*a*) the conventional truck with single pneumatic tires on four wheels, (*b*) dual pneumatics on the rear, and (*c*) trucks with six or more wheels. The company with which I am connected is primarily interested in carrying trucks on pneumatic tires, so it has tried the three possibilities. As

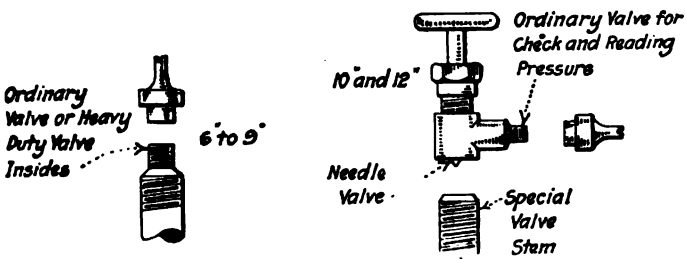
Ordinary Valve for Check and Reading Pressure
10" and 12"
Ordinary Valve or Heavy Duty Valve Insides
6 to 9"
Needle Valve
Special Valve Stem

FIG. 5—VALVE INSIDES FOR DIFFERENT SIZES OF PNEUMATIC TIRE

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a result it looks unfavorably only on the dual pneumatics, two tires on the same wheel. The dual idea was tried and abandoned several years ago, but it crops up now and I want to set the reasons for dropping it clearly before you. The dual tires do not share the load equally, because the inflation is seldom kept alike in both tires and because on crowned roads, and more particularly rough roads, one tire takes more than its share of the load. Dual tires are too easily abused and prove more expensive than either of the other two possibilities.

The company came to realize some time ago that the introduction of the pneumatic tire for motor trucks would have a material bearing upon the design of the truck itself to get the most good from the use of such a tire. For this reason we have been making a study of the problem, and have at this time certain considerations to present.

Factors Influencing Truck Design

The main factors bearing upon the problem of truck design for pneumatic tires are as follows:

(1) Speed, including road and engine speeds, rear-axle gear-reduction and air brakes
(2) Traction, including engine torque and transmission gear-reductions
(3) Shock effects, including stresses introduced and the necessary factor of safety of sprung and unsprung parts
(4) Emergency equipment, including tire pumps and spare tires

Table 7 shows road speeds that I consider satisfactory, together with the usual rear-tire specifications for various sizes of truck. The engine speeds are figured on the basis of 1200 ft. per min. piston speed, which value I believe can be considered a good average. However, some engines on the market may not operate successfully at this speed and again others can stand a higher speed. Higher speeds set up considerable vibration and add discomfort to driving. In general it may be noted that solid-tire gear-reductions range from 7 to 16, whereas recommended ratios for pneumatic tires range from about 5 to 8.

Table 8 shows a study in computed speeds over a given course which corresponds somewhat to the course from Akron to Cleveland, going by the way of Tallmadge in the one case, and by way of Akron's North Hill in the

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TABLE 7

Present Solid Tire Gear Ratios	Solid Tire, Average Governed Speed, m.p.h.	Truck Capacity, tons	Recommended Speed for Pneumatic-Tired Truck, m.p.h.	Rear Tire Size, in.	Speeds		Pneumatic-Tired Truck Rear Axle Gear Reduction
					Rear Wheel, r.p.m.	Engine, r.p.m.	
7	17	1	30	36	280.0	1,450	5 18
8	17	1½	30	38	265.4	1,450	5.47
9	15	2	30	40	252.1	1,325	5.52
10	15	2½	30	42	240.1	1,325	5.26
11 to 12	13	3½	25	44	191.0		6.28
				[a]38	221.1	1,200	5.43
12 to 13	11	5	25	48	175.0		6.86
				[a]40	210.1	1,200	5.72
14 to 16	9	7	20	[a]42	160.1		7. 0
				[a]44	152.8	1,200	7.85

[a]Six-wheel combination.

other. K-1 represents a "standard" make of truck in our transportation service. It will be noted that a normal speed of 25 m.p.h. is required to double the average speed of a solid-tired truck whose normal or governed speed is 11 m.p.h. The reason, of course, is that the solid-tired truck has a higher tractive ability in high gear, and hence is able to maintain its normal speed over a great many grades.

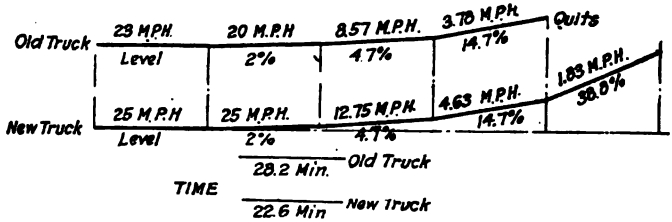

FIG. 6—HOW A STUDY OF GEAR REDUCTIONS SAVES TIME

Fig. 6 shows how time can be conserved by a careful study of gear reductions. The saving on a course 4 miles long with grades as shown amounts to 20 per cent.

On account of the higher speed of the pneumatic-equipped trucks, it is necessary to equip them with brakes having 100 per cent more capacity than is the case with solid-tired trucks. This raises the question of how to apply such a capacity easily. In answer to this I would suggest the application of brakes to the front wheels when all the capacity possible is attained in the rear. Front-wheel brakes are now well developed, due to the use during the war of trailers which required brakes on the steering axles.

When the normal speed has been determined, we may next consider the tractive ability required to get over the road without the inconvenience of shifting gears too often. The tractive factors that I consider desirable and satisfactory are shown in Table 9, figured according to the formula at the head of the table.

The engine torque required to give these tractive factors is also shown together with the sizes of engines on the market today that develop the torque required. There are conditions however where larger engines may be desirable. I believe smaller engines will not give satisfactory speed. The striking difference between tractive factors for pneumatic-equipped trucks and solid-tired trucks can be accounted for by the fact that the former, when approaching a hill, have about four times the mo-

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TABLE 8

	Solid Tire, 1260 r.p.m.		New Job, 1400 r.p.m.		Six-Wheel, 1600 r.p.m.		K-1, 1400 r.p.m.	
	Speed, m.p.h.	Time, hr.	Speed, m.p.h.	Time, hr.	Speed, m.p.h.	Time, hr.	Speed, m.p.h.	Time, hr.
TALLMADGE								
3 miles, 6 per cent grade	6.66	0.45	8.57	0.35	6.25	0.48	8.15	0.37
3 miles, 3 per cent grade	11.00	0.27	17.90	0.16	10.50	0.29	14.10	0.21
34 miles, level	11.00	3.09	25.00	1.36	25.00	1.36	23.00	1.48
Total time	.....	3.81	.....	1.87	.....	2.13	.....	2.06
Average speed	10.50	....	21.40	....	18.70	....	19.40	....
NORTH HILL								
1 mile, 12 per cent grade	3.52	0.28	4.63	0.22	3.47	0.29	3.78	0.26
2 miles, 6 per cent grade	6.66	0.30	8.57	0.23	6.25	0.32	8.15	0.25
3 miles, 3 per cent grade	11.00	0.27	17.90	0.16	10.50	0.29	14.10	0.22
34 miles, level	11.00	3.09	25.00	1.36	25.00	1.36	23.00	1.48
Total time	.....	3.94	.....	1.97	.....	2.26	.....	2.21
Average speed	10.10	....	20.30	....	17.70	....	18.10	....

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mentum of the latter and will negotiate a very large percentage of hills without increased power. However, with the increased power applied they will ascend long steep grades before requiring a shift in gears.

The figures here recommended are based upon numerous trials of trucks of various capacities in our transportation. With the high-gear tractive ability and engine size determined, we have next the low-gear ability to consider. We find a tendency toward a low-gear ratio in the transmission of 6 to 1 in 5-ton trucks. This, in connec-

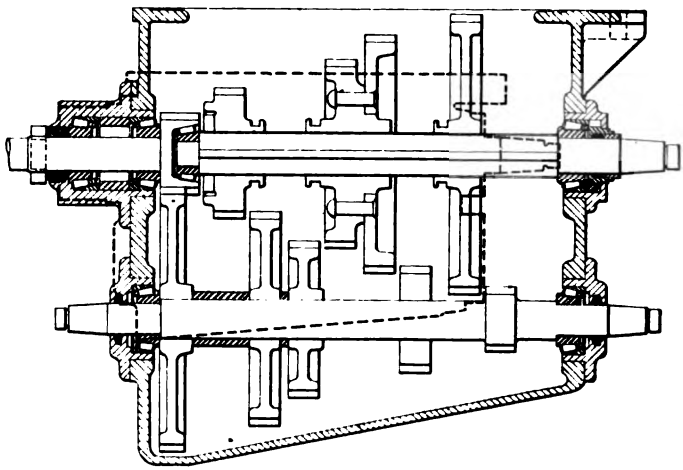

FIG. 7—TRANSMISSION WITH A 14 TO 1 REDUCTION IN LOW GEAR

tion with present solid-tire axle-ratios gives a tractive factor of 0.42. A desirable low-gear ability for trucks equipped with pneumatic tires may be given as 0.50 although I do feel that it should not be less than 0.30.

Table 10 shows the low-gear transmission ratios necessary to give these tractive factors. It will be observed that these ratios are considerably different from present practice. The question naturally arises, how can this best be handled?

Fig. 7 shows a conventional design of transmission to give about 14 to 1 reduction in low gear. Superimposed upon this, in dotted lines, is a regular transmission of about 5 to 1 low-gear reduction, in general use today. By examining this, it becomes evident that such a construction cannot well be considered. The next best and easiest arrangement is as shown in Fig. 8 where we have a

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TABLE 9

Tractive Factor =
Maximum Engine Torque in pound-inches × Efficiency of Transmission (0.90 in high gear, 0.85 in other) × Gear Reduction ÷ Weight of truck and load in pounds × ½ the diameter of rear tire in inches

Truck Capacity, tons	Pneumatic Tire Tractive Factor	Corresponding Solid Tire Tractive Factor	Engine Torque, lb.-in.	Engine Sizes on Market that Develop Approximate Torque Required, in.		
1	0.07	0.085	1,650	3¾x5	4 x5	3¾x5⅛
1½	0.06	0.085	1,950	4 x5½	4⅛x5¼	4⅛x5½
2	0.06	0.083	2,500	4½x6	4½x6¼	4½x5½
2½	0.06	0.082	3,000	4¾x6	4½x6¼	
3½	0.05	0.077	3,000	4¾x6	4½x6¼	
5	0.04	0.070	3,200	5 x6	4¾x5½ (6 cyl.)	
7	0.04	0.060	3,300	5 x6	4¾x5½ (6 cyl.)	

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TABLE 10 —TRANSMISSION LOW GEAR REDUCTION

Truck Capacity, tons	Low Gear Tractive Factor	Engine Torque, lb.-in.	Total Gear Reduction	Rear Axle Reduction	Transmission Reduction in Low Gear	Trans. Redn. 0.30 Tractive Factor
1	0.50	1,650	49.1	5.18	9.47	5.68
1½	0.50	1,950	51.0	5.47	9.32	5.58
2	0.50	2,500	49.5	5.26	9.42	5.64
2½	0.50	3,000	51.7	5.52	9.37	5.62
3½	0.50	3,000	61.4	5.43	11.30	6.77
5	0.50	3,200	79.7	5.72	14.00	8.40
7	0.50	3,300	105.0	7.50	14.00	8.40

three-speed unit transmission of regular design in combination with an auxiliary transmission having 3½ to 1 reduction which, combined with the 4 to 1 low-gear reduction in the unit set, gives 14 to 1 total transmission low-gear reduction. Dotted lines in the figure show the unit and auxiliary, whereas the light full lines represent the standard amidships construction. Fig. 9 shows a more compact gear-set system that involves the combination into one of the two sets above mentioned.

We will next take up the consideration of allowable stresses. Any fixing of allowable stress requires an investigation of the cushioning effect of pneumatic, as compared with solid, tires.

Fig. 10 shows the rate of deflection of the pneumatic tires and their corresponding solid tires, together with a curve showing how the solid tire depreciates in resilience with age and wear. It will be seen here that for a

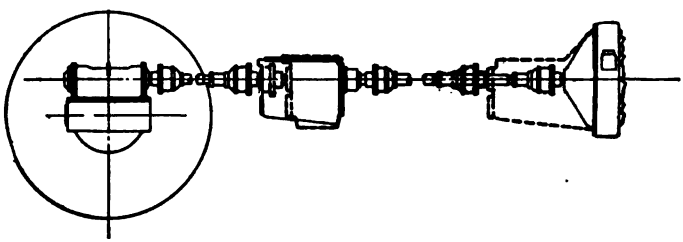

FIG. 8—OBTAINING A 14 TO 1 LOW-GEAR REDUCTION BY EMPLOYING TWO TRANSMISSIONS

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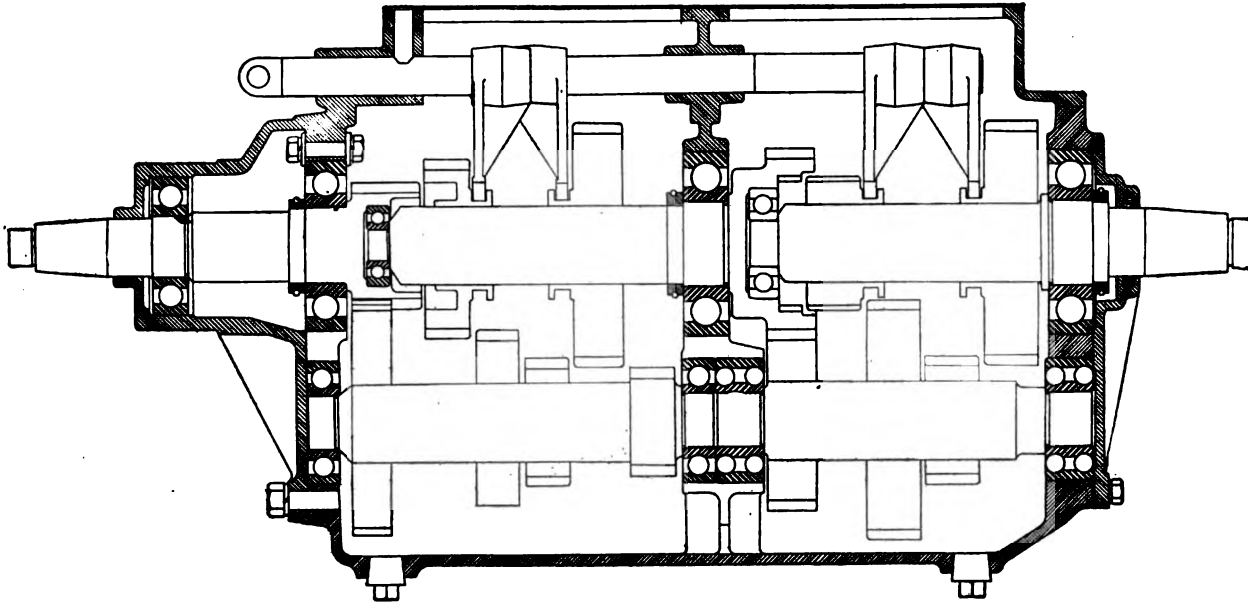

FIG. 9—A COMPACT GEAR-SET IN WHICH THE MAIN AND AUXILIARY TRANSMISSIONS OF FIG. 8 ARE COMBINED INTO A SINGLE UNIT

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given load the pneumatic tire deflects four times as much as a solid tire.

On this basis, Fig. 11 indicates that the stresses in unsprung parts due to shock, build up to the same amount whether pneumatic or solid tires are used. There is, however, a difference in the time element; that is, the time required to build up the stress due to shock is twice that of the solid tire, in the case of pneumatic tires. If any reduction of the factor of safety is justifiable, it appears that it is to be done on this basis. As yet we have been unable to conceive a method of testing or experimenting that will prove conclusively how much the factor of safety can be changed because of this time element. Any suggestions along this line will be appreciated. I have, however, taken a 2-ton chassis and installed engines designed for 3-ton trucks, and made the trucks haul 3½ tons of freight very successfully. From numerous other trials like this I conclude that if a factor of safety of 6 is safe with solid tires, a factor of 5 can be allowed for pneumatic equipment. This refers mainly to unsprung parts. Regarding sprung parts, it is difficult even to estimate the allowable stresses. It appears that the factor of safety can be reduced but not so much as in the case of unsprung parts. For instance, with pneumatic tires, the frame is not deteriorated by shocks in the same manner as when solid tires are used, the rivets stay tight, etc. Fig. 12 shows how the engine is cushioned by the pneumatic tire.

Emergency Equipment

The method of carrying spare tires is quite a problem. However, it is worth while to make provision for carrying this spare equipment when designing the body or chassis. Probably the best solution is to place a compartment directly back of the driver's seat so that the tire can be removed and replaced without disturbing the pay load. The next best place is under the chassis frame at the rear and at the side opposite the muffler.

A power-driven tire pump is indispensable when pneumatic tires are used for the main reason that the truck cannot be moved any distance on a deflated tire without causing serious damage. Even though the truck is equipped with demountable rims and inflated spare tires are carried, there will be times when a single use of the air pump will be worth the cost of the pump. Having the tire pump installed on the truck will facilitate keep-

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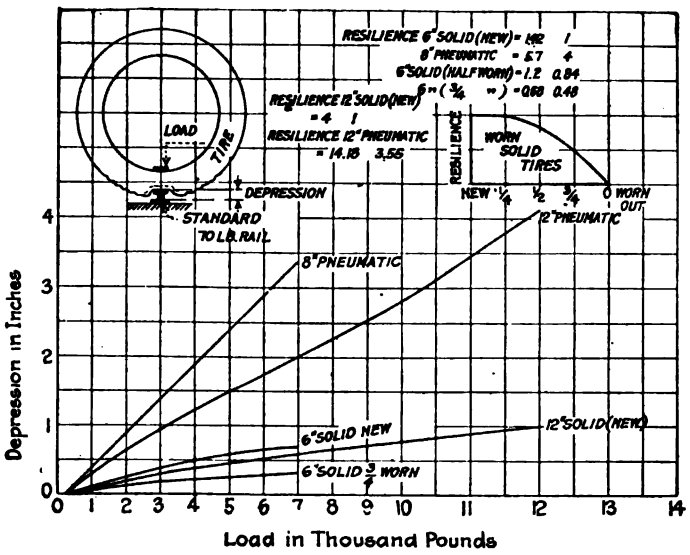
RESILIENCE 6" SOLID (NEW) = 1.82 1
8" PNEUMATIC = 5.7 4
6" SOLID (HALF WORN) = 1.2 0.84
6" (¾ ") = 0.68 0.48
RESILIENCE 12" SOLID (NEW) = 4 1
RESILIENCE 12" PNEUMATIC = 14.18 3.55
LOAD
TIRE
DEPRESSION
STANDARD 70 LB. RAIL
RESILIENCE
WORN SOLID TIRES
NEW ¼ ½ ¾ 0 WORN OUT
12" PNEUMATIC
8" PNEUMATIC
6" SOLID NEW
12" SOLID (NEW)
6" SOLID ¾ WORN
Depression in Inches
Load in Thousand Pounds
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

FIG. 10—COMPARISON OF THE RATE OF DEFLECTION OF SOLID AND PNEUMATIC TIRES

ing the tires properly inflated and produce better tire mileage; this factor alone will easily overcome the cost of the tire pump and in addition yield good returns. This pump should be designed to drive from the transmission. At least this is preferable; a pump mounted on the engine adds to the congestion under the hood, and the small shaft available, already carrying the water pump and magneto, is not strong enough for an air pump. The pump can best be air-cooled, due to its intermittent service and the difficulty of embodying any efficient water-cooling arrangement without much expense. Also, its lubrication should be well worked out, with a view toward avoiding any oil discharge that would injure the inner tube. The speed at which the pump is to operate should not exceed one-half of the governed engine speed and in no case should it be over 600 r.p.m. The pump should operate to permit complete inflation of a 10-in. tire in approximately 10 min. This figure is being realized by several pumps now on the market.

It is worthy of note that a 44 by 10-in. tire contains 5700 cu. in. of air space. The area of the orifice through which the air must pass in a standard tire valve is 0.00307 sq. in. Hence, if a pressure of 200 lb. per sq. in.

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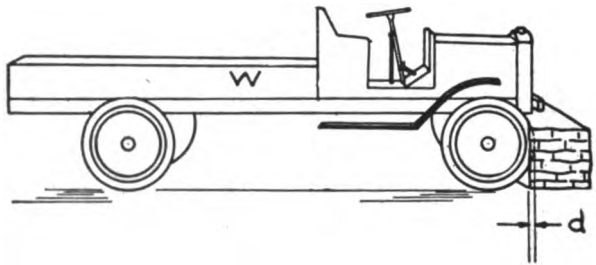
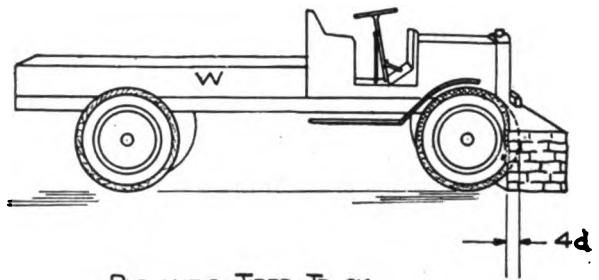
12.5 M.P.H.



SOLID TIRED TRUCK

25 M.P.H.



PNEUMATIC TIRED TRUCK

$$E = \frac{WV^2}{64.4}$$

$$E_s = \frac{20{,}000 \times 18.3 \times 18.3}{64.4}$$

$$= \frac{6{,}700{,}000}{64.4}$$

$$= 104{,}000 \text{ Ft.-Lb.}$$

$$E_p = \frac{20{,}000 \times 36.6 \times 36.6}{64.4}$$

$$= \frac{26{,}800{,}000}{64.4}$$

$$= 419{,}000 \text{ Ft.-Lb.}$$

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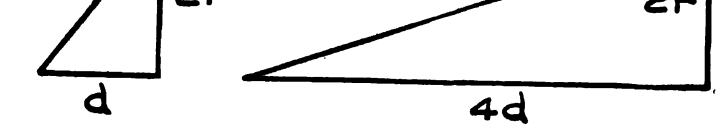

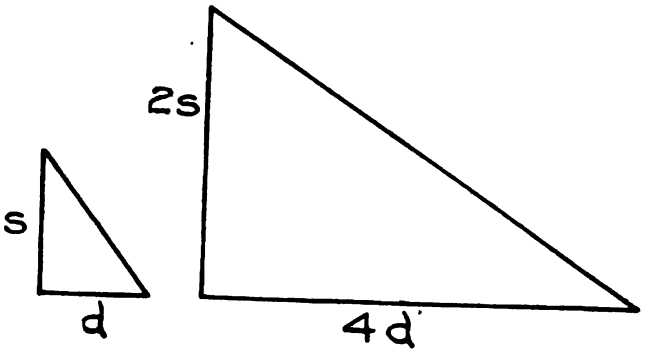

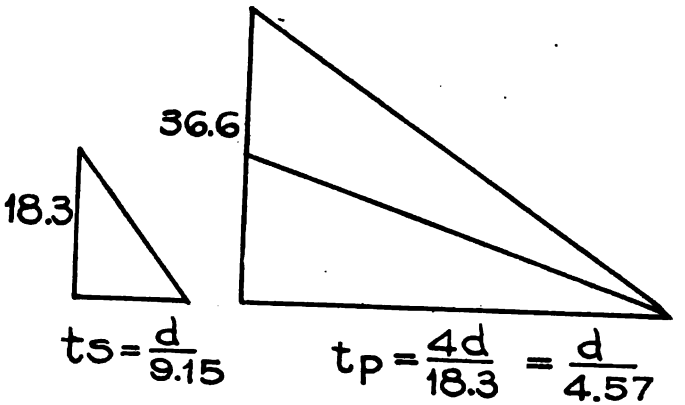

$$ts = \frac{1}{2} tp$$

F_d = Work done in stopping truck
$= F_s = F_p$

$$F_s = \frac{104{,}000}{d}$$

$$F_p = \frac{419{,}000}{d}$$

$$\frac{104{,}000}{d} = \frac{419{,}000}{d}$$

FIG. 11—BUILDING UP OF STRESSES IN UNSPRUNG PARTS BY SHOCK

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upon this orifice is assumed, the minimum time of inflation of a 44 by 10-in. tire would be about 6 min.

It is debatable whether a two-stage pump is necessary in this service. Certainly, present design would not indicate this to be true, as there are single-stage pumps quite as efficient as any two-stage, for this relatively small volume. It is suggested that the air intake on the pumps be piped to a clean point on the truck, perhaps under the seat, thus preventing dirt from being sucked into working parts. At least 6 ft. of copper tubing should be placed between the pump and the hose, to avoid burning off the latter. The advisability of placing a small receiving chamber in the line has been suggested. This would equalize the air pressure and assist in reducing the excessive temperature of the air delivered.

New Six-Wheel Truck

It may interest you to know that my company has under construction at present two 5-ton trucks of six-wheel design. These trucks will have the following specifications:

Engine, 5 by 6 in.; four-cylinder
Transmission, unit powerplant and auxiliary; 14 to 1 low-gear reduction
Rear axle, Goodyear tandem rear. Made up of two worm-drive axles, intended for use on 1½-ton solid-tire trucks in one case, and two internal-gear axles of the same rated size in the other. The rear-axle gear-reduction is 5.8 to 1
Front axle, intended for a 3½-ton solid-tire truck
Frame, 3 by 7 by ¼ in., pressed steel
Tires, 40 by 8 in. pneumatic; six in all

On account of the large size and weight of the 48 by 12-in. pneumatic tire for the 5-ton trucks, it was necessary to consider the application of four tires to the rear of the truck, instead of having two of the excessively large ones. The first attempt at an arrangement for applying four small tires to the rear, without using dual tires, which is considered out of the question, is shown in Fig. 13. This consisted of a more or less standard rear axle with a walking-beam adapted to each end and with the wheels mounted upon trunnions from this walking-beam, the springs being mounted upon the axle and attached to the frame on the inside. A chain drive, which, by the way, is about the only feasible drive with this arrangement, was used. This construction ran success-

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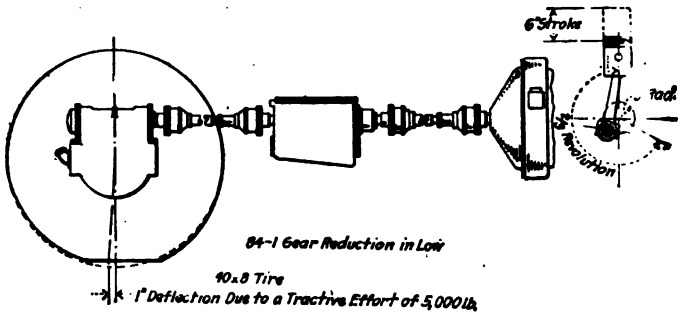

FIG. 12—CUSHIONING THE ENGINE BY A PNEUMATIC TIRE

$$n = \frac{t}{c}, \text{ and}$$

$$t = \frac{d}{s} \times g \times c, \text{ where}$$

n = Revolutions of engine due to circumferential deflection of tire
t = Travel of crankpin
c = Circumference of crankpin circle
d = Circumferential deflection of tire
s = Circumference of tire
g = Total gear reduction

$$t = \frac{1}{40 \times 3.1416} \times 84\ (6 \times 3.1416) = 12.61$$

$$n = \frac{12.61}{18.85} = 0.67$$

fully for about 10,000 miles before a serious failure occurred. Some inconvenience was caused by having the chains jump off and inability to get a brake mechanism that would work. The main point against this design is its enormous weight; however, it served to show that satisfactory tire mileage could be secured from such an arrangement and that there was a good possibility of adapting four relatively small tires to the rear wheel. To develop further this point, the tandem-axle construction, shown in Figs. 14 and 15, was built up. This construction appears to have good possibilities and has at present operated about 3300 miles, 1000 to 1200 miles of which has been on an entirely rough and uneven country road, so rough in fact that it was difficult to keep the front spring tight. The principle of construction can easily be seen by referring to the illustration. It consists of two small live-axles, with inverted springs pivoted at the center upon the frame and with the ends resting upon the

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axles. The axles are tied together by crossed torque-rods. The drive is passed through the forward to the rear axle by a short propeller-shaft.

Fig. 16 indicates the possibility of using four springs to tie the axles together and is a very feasible construc-

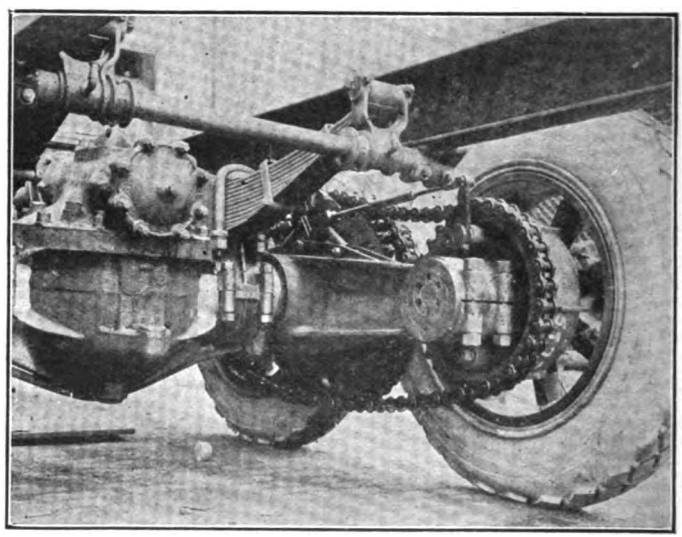

FIG. 13—FIRST ATTEMPT AT USING FOUR SMALL TIRES FOR THE REAR OF A SIX-WHEEL TRUCK

tion to use in connection with the tandem rear-drive. While the drive described here is worked out for a truck of 5-tons' capacity, it is equally applicable to one of 7-tons' capacity. Some of the advantages the six-wheel truck has over the regular type of the same capacity, on 48 by 12-in. pneumatic tires, are:

(1) Saving in cost
(2) Reduction in weight
(3) Reduction in axle cost
(4) Increased traction
(5) Better riding qualities
(6) Less damage to roads
(7) Larger brakes
(8) Greater operating radius

Compared to the pneumatic-tired four-wheel truck using tires of large diameter, namely 48 by 12 in., the

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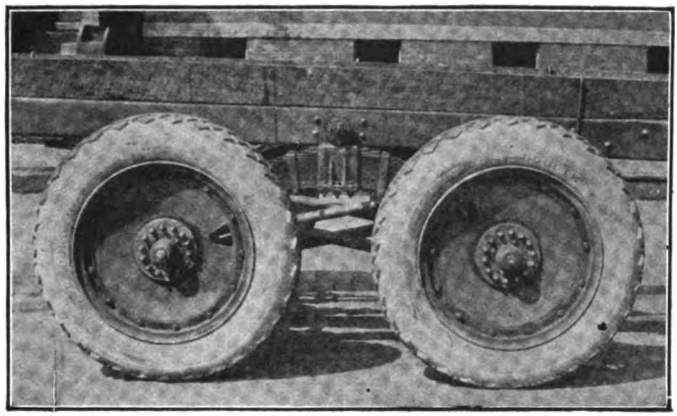

FIG. 14—SIDE VIEW OF THE TANDEM-AXLE CONSTRUCTION THAT WAS DEVELOPED

saving by using four smaller tires is about $500; sufficient to purchase three or four complete spares.

Each 40 by 8-in. tire weighs only 119 lb., whereas each 48 by 12-in. tire weighs 398 lb. Carrying a spare tire in

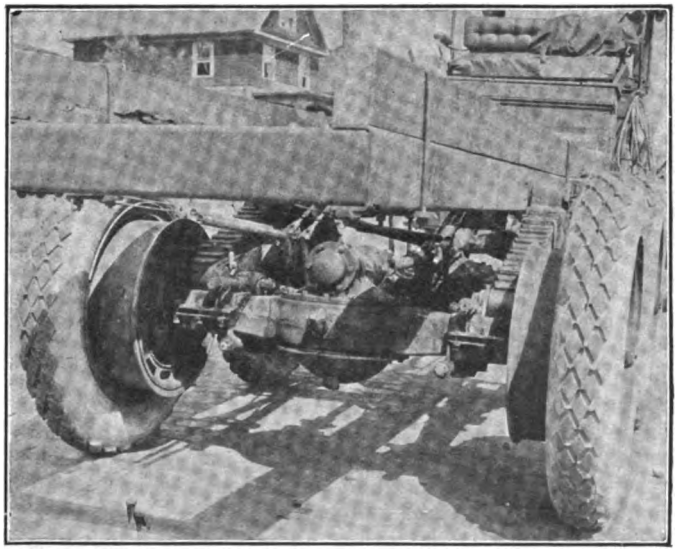

FIG. 15—VIEW LOOKING FROM REAR OF THE TRUCK AT THE TANDEM AXLE

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each case, the total weight reduction in tires alone amounts to over 500 lb. in favor of the 8-in. size. Then again, the 8-in. spare can also be used as a front-wheel spare; this reduces the tire investment still further.

The use of two rear axles in tandem, results in the employment of small axles which are in large production with consequent lower costs, instead of the large sizes that are made only in small quantities with relatively high costs. The actual saving amounts to about $120 per truck. This means that the tandem rear-drive mechanism costs somewhat less than standard two-wheel rear-drive for heavy trucks.

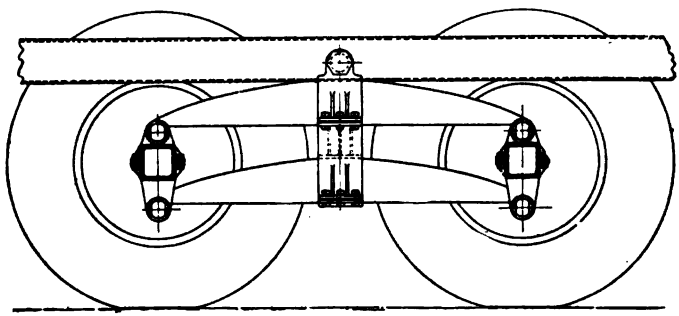

FIG. 16—FOUR SPRINGS USED TO TIE THE AXLES TOGETHER IN THE TANDEM-AXLE CONSTRUCTION

While four 8-in. wheels with the brake-drums, etc., weigh 77 lb. more than the same truck equipment for 12-in. tires, there is a saving in weight of 1203 lb. per truck. The details of this reduction are given in Table 11.

As compared with a solid-tired truck of equal weight capacity, we have the savings given in Table 12.

The area of ground contact of four 8-in. pneumatic tires is about 27 per cent greater than that of two 12-in. pneumatics. This additional surface keeps the tires from sinking in soft places, gives better traction under conditions when most needed and in ordinary service the additional area gives better traction. As compared to solid tires in winter service, off of paved roads, etc., the four pneumatic tires have all of the advantage.

The tandem rear drive has about the same advantageous effects over single-axle construction that the pneumatic would have over solid tires. With the tandem com-

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TABLE 11

	Lb.
Weight of 5-ton truck axle, exclusive of brake-drum	1,660
Weight of two 1½-ton solid-tire axles, exclusive of brake-drum	1,200
Saving in axle weight	460
Saving in weight of tires	520
Total saving	980
Less excess wheel and brake-drum weights	77
Net saving in weight due to use of 8-in. tires	903
Saving in weight of radius-rods, springs, etc.	300
Net total saving in weight	1,203

bination, when passing over an obstruction in the road the chassis is raised only one-half the distance it would be in the regular type of construction. This reduces the acceleration of bodies upon the chassis to one-fourth that with ordinary construction. Thus, by reducing shocks and vibration, the number and cost of repairs due to fatigue of metal, etc., are reduced by a large percentage.

The tandem construction makes for such exceptional riding qualities that a glass filled with water to within 1 in. of the top, attached to the rear of the six-wheel truck, lost none of its contents even when operated over a decidedly rough and rocky road.

The most destructive factors of the operation of vehicles upon pavements are the wheel-load and the wheel-thrust. Therefore, if one of two tires under the rear end of a standard 5-ton truck bears down upon the road with a pressure of 8000 lb., it will find a great many places where the road will allow it to crush through and once the break is accomplished a rut or chuck-hole is started. However, if this single tire is replaced by two that are separated a considerable distance, the pressure of each of the smaller tires becomes 4000 lb. upon the pavement in-

TABLE 12

	Lb.
Weight of two 48 by 12-in. solid tires and wheels	1,262
Weight of four 40 by 8-in. pneumatic tires and wheels	1,208
Excess weight of solid-tire equipment	54
Saving in weight of axle	460
Saving in weight of springs, radius-rods, etc.	300
Total saving over solid tires	814

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stead of 8000 lb. and a place in the road that will break through is seldom found.

This tandem rear-drive cuts in two the heavy wheel-loads and the thrust as well, thereby making it possible to design pavements suitable for 3½-ton trucks, and carry 5 and 7-ton loads upon them with no increase in their destruction.

The tandem-axle combination has a decided advantage over both the regular pneumatic and solid-tired types in that four brakes of 21-in. diameter are available in place of two brakes of 21-in. diameter, the maximum possible with the two-wheel rear-drive type.

Pneumatic tires permit of an increase in the average speed to just double that with solid tires and the tandem rear-drive will permit increased minimum speeds on bad roads, rough streets, etc. In view of the fact that the trucks now building are for the purpose of demonstrating these points, I am very desirous that you gentlemen suggest tests that you consider would prove the points that are yet open for proof.

Summary

The design of the ultimate motor truck to use pneumatic tires will in general require the following changes from present solid-tire design:

(1) Considerably higher rear-axle gear-reductions, ranging from 5 to 8 for pneumatics as against 7 to 16 for solid tires

(2) About 15 per cent increase in engine sizes

(3) Lower transmission low-gear reductions, ranging from 9 to 14 for pneumatic as against present solid-tire practice of 3 1/3 to 6. This will automatically introduce a fifth speed, which will account for better average road speed

(4) Lighter unsprung parts such as front and rear axles and wheels

(5) Multiple-wheel construction to accommodate the heavier tonnage, securing the advantages of pneumatic-tire equipment

THE DISCUSSION

T. Kargau:—I was privileged recently to see some of the original data used by Mr. McCreery in his paper. His associates were devoting much time to an analysis of the performance of pneumatic tires which they dis-

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tributed to replace solid tires. In several cases the Goodyear Company has substituted pneumatic for solid tires with the intention of running a six months' test, one-half or one-third of each fleet being equipped with pneumatics. After one month the owners of the fleets in many cases would not allow the tests to continue, but changed over all trucks to pneumatic tires because they could not afford to let the others run on solid tires. The costs in all cases were kept according to the National Standard Truck Cost System. When I saw some of the figures I could scarcely believe them. Occasionally a 30 per cent saving of gasoline was shown and a few instances were given where perhaps 50 per cent of the oil was saved. Owners have perhaps over-estimated the mileage in some cases, but there is little doubt that many of these tires have run more than 20,000 miles.

It appears to me that Mr. Norton is absolutely correct in making the statement that the pneumatic field is open and that two years hence everything up to the 2-ton size will be pneumatic-equipped. There are some serious objections to what is being done with pneumatic tires by certain companies at present. There is a tendency, at least among salesmen, to place the speed limit on pneumatic tires at about 40 m.p.h. The average truck on the market today, if it were traveling 40 m.p.h., would require service, and emergency and a few other brakes to hold it if it had to be stopped quickly. That is the one outstanding feature regarding changing to pneumatic equipment; the present brake equipment will prove inadequate at high speeds.

A MEMBER:—What experience have the users had in keeping the pneumatic tires on trucks properly inflated? What effect do properly or improperly inflated pneumatic tires have upon the steering apparatus?

O. C. BERRY:—How does Mr. McCreery explain a seeming discrepancy in the evidence. Tables 2 and 3 show that when the trucks were equipped with pneumatic tires they used less gasoline and less oil than with solid tires. Granting that the use of pneumatic tires will result in the truck requiring less power when running at an ordinary speed on a good road, it may nevertheless be pointed out that it will require an equal amount of power to start the load or to get through a very difficult piece of road; so that, no matter whether pneumatic or solid tires are used, the trucks must be equipped with engines having the same power capacity. The pneumatic

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tires will therefore result in the standard truck engine running under a lighter load, or at a higher speed, or both.

My experience with engines indicates that they do not use less oil at light than at heavy loads. If the oil used be expressed in pounds per 1,000,000 revolutions, or in pounds per truck-mile, the amount used will not vary very much as the speed of the engine is changed, and will not decrease as the load is decreased. It is therefore easy to understand why the pneumatic tires would cause the truck to run more miles per gallon of gasoline, but hard to account for the use of less lubricating oil, unless there is some other factor involved that is not indicated in the paper. In view of the extreme difficulty that is always encountered in controlling the running conditions in road tests, I therefore inquire whether in the opinion of Mr. McCreery the tests were checked sufficiently to substantiate the fact that the results reported in Tables 2 and 3 are characteristic and that pneumatic tires do result in the use of less lubricating oil.

N. B. BURKNESS:—I know of a case where seven first-class 2-ton trucks equipped with solid tires were re-equipped with pneumatic tires. The speed limit in the locality was 28 m.p.h. The seven trucks exceeded that limit invariably.

A MEMBER:—If the standard solid-tire equipment is changed to pneumatic, the load capacity of the truck is increased invariably. What reasons can be given for this?

W. G. WALL:—What data are available as to the comparative ability of a truck equipped with solid and one with pneumatic tires, to go through rough roads and mud? I observed some interesting tests made about three years ago, which I believe Colonel Slade conducted. He had four or more different makes of truck, two of each. One of each make was equipped with pneumatic and the other with solid tires. The pneumatic tires performed remarkably well on all the good roads. There was no question that the pneumatic tire seemed to come out ahead in all the good-road tests. I was rather surprised, however, when the ability of these tires to go through mud was tested. The ground they were pulling through was rather soft, and the wheels sank in from 10 to 15 in. Ability was shown by the distance they were able to go without stalling the engines. That distance seemed to be exactly the same with pneumatic or solid

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tires. The various makes of truck went different distances, but all became stalled eventually, so it was difficult to judge whether there is really any difference in power required between the pneumatic and the solid tires, in pulling through mud. During the tests both seemed to sink down the same distance and both showed that they required about the same amount of power to get them through.

PRESIDENT VINCENT:—Did both the trucks have the same gear ratios?

MR. BURKNESS:—The ratios were the same. The solid tires were 36 by 6 in. and the pneumatic 38 by 7 in.

CHARLES GUERNSEY:—I believe that the analysis of this problem as presented by these two authors will be of considerable benefit. The matter of steering was mentioned in Mr. McCreery's paper. It has been our experience that trucks equipped with pneumatic tires steered considerably harder, even when the tires are highly inflated, than the same trucks when equipped with solid tires. I agree with the authors in their statement that it will be necessary to design trucks specially to meet the new conditions created by the use of pneumatic tires. One of the most important advantages of the pneumatic tires is the increased speed which they permit. To realize on this advantage it is necessary to design the truck to fit the conditions.

Mr. McCreery prophesies a material saving in weight when trucks are designed solely for pneumatic tires. It is my belief that, while weight may be saved at some points, it must be added at others and that, given the same standard of engineering, the pneumatic-tired truck will weigh practically the same as the solid-tired truck of the same capacity.

Some time ago I made an analysis of practice in the design of front-axle centers and found that it was common to use stresses in passenger-car design which were higher than the stresses in solid-tired truck design in the ratio of 10 to 8. This would indicate that all load-carrying members might be made 20 per cent lighter in the case of pneumatic tires. As a matter of fact, however, the size and weight of a number of these load-carrying parts are determined by manufacturing conditions rather than by stresses. It would appear, therefore, that we can expect a saving in weight of something less than 20 per cent of the load-carrying parts, such as

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axle centers, spindles, rear-axle housings and spring shackles.

On account of the higher speed of pneumatic-tired trucks, it is necessary to increase the gear ratio materially to keep the engine speed within reason. This requires that larger engines be used. These large engines in turn necessitate more radiation, heavier clutches and transmissions and propeller-shafts. In fact, the power line will need to be made heavier all through. The increased weight of the heavier engine, transmission, clutch, etc., will more than offset any saving in the axle load-carrying members. Weight can undoubtedly be saved by the substitution of lighter materials of construction, but this change is not affected by the tire situation.

As regards the possibilities of various sizes of tires, I believe that neither of the authors will take exception to the statement that tires 44 by 10 in., or larger, cannot be satisfactorily used in any great number of cases. It would therefore appear that the possibilities of dual pneumatic tire equipment or the six-wheeled truck, mentioned by Mr. McCreery, need to be watched.

G. L. LAVERY:—The subject of steel wheels is pertinent to the matter Mr. McCreery speaks of, but it has not been mentioned by him in his remarks on pneumatic tires for trucks. Much weight can be saved on wheels for pneumatic tires compared to what is required with wheels for solid-tired trucks. Solid-tire wheels must be made very strong, much stronger than would ordinarily be necessary, as, in cases where the tires are worn down to the tire band, the load has to be carried on the wheels themselves to bring the load home; with pneumatic tires the wheel can be made as light as it can be run when cast in the foundry. In the case of the 38 by 7-in. demountable wheel the weight of the wheel itself, with the hub cast integrally with the wheel, is about 72 lb. less than the weight of the demountable rim that surrounds it. The solid-tire wheel of the same capacity will weigh from 260 to 300 lb.

The brakes on the "ultimate" truck will need to be of a different character from that of those now in use, because the wheel diameter for pneumatic tires has been established at 24 in., irrespective of the size of tire. The inner diameter of the brake-drum used at present on the 5-ton truck is larger than the diameter of the pneumatic-tire wheel and, in designing the new type of brake-drum

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the outside diameter of the wheel should be considered.

F. J. SULLIVAN:—In using pneumatic tires is it necessary to have longer bearings on the wheels owing to the thrust produced in turning corners? Is it not a fact that the larger tires are subject to trouble caused by the sidewalls cracking because of going through deep ruts? Why do the smaller 36 by 6-in. or 38 by 7-in. cord tires stand up better?

L. C. FISK:—Has Mr. McCreery noticed any difference in bearing performance in the trucks that have been making the long haul between Akron and Boston? Have the bearings given trouble or has their performance been better than might have been expected if the trucks had been equipped with solid tires?

E. T. BIRDSALL:—I know of a well-known truck manufacturer who never used any pneumatic tires until last year. The company had been exceptionally free from front-spindle trouble. Its front axles and spindles had been made very heavy and of a good grade of alloy steel. Since its customers have put pneumatic tires on some of the trucks a number of front spindles have broken. It seems to me that this is due primarily to the increase in speed; it would appear that when the speed of the trucks is doubled, the road shocks are more than doubled. I have no accurate data in regard to that. In general, I believe that the pneumatic-tired truck is the coming truck. I have ridden on the six-wheel truck, and I am convinced that it has good possibilities.

At present we are thinking mainly of freight-carrying trucks, but I believe that one of the largest fields that is about to be developed is that of the large omnibus. There is no question that we can operate omnibuses in congested districts better than we can cars on rails. I say that from a fifteen-year experience in the street railway business, and about the same or more in the automobile business. For the large omnibuses carrying thirty or forty passengers, the six-wheel idea offers many advantages. At the Goodyear plant in Akron we rode along smoothly over rough roads on six wheels, although we were sitting on sandbags and the springs were none too good; the performance was really wonderful. If anyone has mentally compared changing those 48 by 12-in. tires, and the 40 by 8-in. size, and can imagine being out in the country with one or the other to fix, there would be no question as to choice.

E. A. BELL:—It might be of interest to know what

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the actual experience of my company has been with the pneumatic tire. We had five trucks. They were operating in Australia and were originally fitted with pneumatic tires. After two years of operation we found we had had to renew the rear axles and bearings twice. I decided to change the bearings. The size of the tires, when fitted, slightly raised the ratio. We found after twelve months' operation that we were actually 8 to 9½ per cent better off regarding gasoline consumption.

Regarding the steering, we found it undoubtedly easier. As to bearings, after two years' further operation with the pneumatic tires, we had no need to renew a single bearing in the five rear axles. Previously, with solid tires we had had two sets of bearings.

We found it necessary to use what we call security bolts on the tires in traveling on rough roads; otherwise we were continually ripping the valves out. We used the beaded-edge tire.

In reference to the remark in Mr. McCreery's paper that it is very rarely found that the pneumatic tire goes flat suddenly, our experience has been that if it gets a puncture, the tire is flat before it goes many feet farther and in almost every case it requires a new section. In fact, when the tire goes flat, it goes very quickly. Those have been our actual experiences in Australia.

E. E. WEMP:—We have very recently developed, and are marketing a 1½-ton speed truck. Our experience thus far has shown a very decided advantage in the use of pneumatic tires over solid-tire equipment. We have been able to improve the gasoline economy, and the general wear-and-tear on the chassis has been apparently materially reduced on account of the better suspension.

In the development of the job it was our purpose to hold the chassis weight down, and very careful consideration was given to details of construction whereby the weight would be reduced without sacrifice of strength. The reduction of weight was accomplished very largely by careful design and without resorting to other than conventional materials. In this regard it is our opinion that the weight can be reduced considerably more by the judicious use of aluminum, in place of malleable castings, cast iron and the like. After listening to the paper and the discussion on the use of aluminum in axles, and particularly in wheels, it would seem that there is a possibility of making a considerable reduction in weight by the use of aluminum for those parts. In general, I

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believe the industry is becoming aware of the importance of reducing chassis weight to the minimum, and that great progress will be made in the near future toward the accomplishment of this purpose.

Another point which I believe will stand investigation on the part of engineers is the weight of commercial-vehicle bodies. It would seem in looking over conventional body construction that less progress has been made in the art of body design than in any other element of chassis development. The bodies of today are built along the same lines as those of the preceding decade, and it would seem that the standard body allowances as established by the National Automobile Chamber of Commerce will require a revision in view of the development of high-speed pneumatic-tired vehicles. After considerable investigation along these lines it would appear that the proper selection of body materials and the disposition of the materials, so as to obtain maximum strength with minimum weight, will make it possible to reduce body weights, particularly in the smaller sizes, from 20 to 30 per cent.

The problem of ample braking capacity is one of the most serious ones encountered in the design of the high-speed pneumatic-tired truck. The kinetic energy of the vehicle increasing as the square of the velocity makes the problem of braking one that is most pertinent.

The question of final-drive on comparatively light high-speed trucks is one which can be given a great deal of attention. At present chassis of this character having a capacity of ¾ ton are ordinarily equipped with a plain bevel-gear type of axle, and the necessary ratio is obtained in one reduction. When the capacities are increased to 1½-ton, it is rather hard to obtain the necessary ratio with a bevel-gear drive. Much thought is being given to this problem, at least in an experimental way, whereby the maximum ratio obtainable in a bevel-gear drive has been very considerably increased. It may be that with further work in this direction the solution of the rear-axle problem for a vehicle of 1½-ton capacity will lie in the bevel-gear type. It might be possible to accomplish the results by a reduction at the rear end of the transmission and a second reduction through the ordinary type of bevel-gear axle. This would permit a large variety of speed ratios within the range of bevel-gear sizes commercially available at this time. It would incidentally reduce the weight of the axle, which nat-

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urally is an advantage inasmuch as the mass of the axle in itself is unsprung.

I was very much interested in the description of the six-wheel-drive truck, having a capacity of 5 or 6 tons and mounted on 40 by 8-in. tires, both front and rear. This design would appear to be a step in the right direction for solving the problem of heavy-duty pneumatic-equipped trucks. Undoubtedly there are many problems in the design yet to be solved, but fundamentally the idea appears to be sound and it may be that in the final analysis the cost of the bevel-axle equipment in the rear, together with smaller wheels and tires, will compare favorably with single-axle construction, necessarily of greater weight and cost. From the standpoint of tire replacements on the road the advantage of a smaller tire is obvious.

The next few years are bound to see tremendous development in the use of pneumatic-equipped trucks.

C. M. McCREERY:—One point was brought up regarding solid tires and pneumatic tires stalling under approximately the same conditions. The remedy for that, as I see it, is a limitation of both the motive power and the gear ratio. In other words, our rear tires have been stuck many times; we have had cases where we had insufficient power to pull out.

As to the matter of using lighter parts in trucks on which pneumatic tires are used, theory is one thing and actual practice another. Theory would naturally indicate that, due to the higher speeds, stronger and heavier parts are necessary, but in the absence of any development along this line we undertook to use lighter parts, making use of standard chassis parts. One of the first things we did was to use a 3½-ton truck frame for 5-ton work, much against the wishes of the original designer of the truck. We operated that truck for 60,000 to 90,000 miles under typical demonstrating conditions with no effect on the frame whatever. We then went down to a 2-ton frame, in the face of constant warning, and that 2-ton frame is in service now; it has gone from coast to coast. We have noted nothing that indicates trouble with the frame.

I believe that the same thing applies to the steering apparatus. Pneumatic tires have more ground contact than solid tires, but there is an appreciable amount of resiliency that absorbs ground friction. I think it could be shown theoretically that steering ought to be harder.

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As Mr. Bell says, the trucks do steer easier. I do not know why. On the Boston run our drivers are able to make turns safely that they are not able to make with solid tires.

As far as the bearings are concerned, it has not been our experience that we need to change the bearings at all. Of course, much of the status of information on this subject is due to lack of research on the part of the bearing companies. The roller-bearing companies have taken the matter up in the last two or three months. From the preliminary investigation of one bearing manufacturer the solid tires require 20 per cent larger bearings than the pneumatic tires require.

As far as the other parts of the motor truck are concerned, there has been very little thought given to what is necessary, for the reason that most of these truck manufacturers have not taken the subject seriously and have waited.

I am very much inclined to agree with Mr. Wemp in the matter of body design. The time necessary to remove a tire is difficult to estimate. I favor the demountable rim. With some of these it is easily possible to change in less than 30 min. I think that has been demonstrated by numerous truck operators. With various detachable tires truck operators take from 1 to 3 hr. to change them, depending largely upon the pump equipment used in connection with the tire. The air-pumps have been one of the bad features.

MR. SULLIVAN:—To put my question more clearly, the Goodyear Company had four wheels driving and two steering; was that to improve the riding quality or to ease the strains on the walls of the tire? Using four driving tires the walls were reduced in size and not so apt to tear.

MR. MCCREERY:—We believe that the larger size pneumatic tires are not as practical as four smaller tires. I mean specifically that the 48 by 12-in. tire, which is used on the 5-ton truck and cannot carry more than the others do, is too heavy for one man to change on the wheel. It costs more than the average truck operator can afford to pay. Moreover, it raises the center of gravity to a point that, while not at all dangerous, is not desirable. It necessitates a radical change in gear ratio.

We are able to equip this particular six-wheel truck with 8-in. tires, which are very much lighter in weight.

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We can reduce the weight approximately 800 lb. below that of a standard solid-tire 5-ton truck. We can use two axles, four wheels and four brakes of 21-in. diameter, in place of two axles and two wheels, and that whole equipment costs no more than the corresponding parts of a standard solid-tired 5-ton truck. That answers the question of brake capacity. We are able to stop the truck in 60 ft., from a speed of 25 m.p.h. Moreover, we get easier riding, a saving of the load itself, and a saving of the road.

S. V. NORTON:—I want to pay a high tribute to the company represented by Mr. McCreery for the manner in which it has attacked this problem. I think it represents a spirit of progress, of vision and of determination to advance the industry, which is not only very creditable but exceedingly brilliant and forceful. I will define what I conceive to be the difference between Mr. McCreery's position and mine in the treatment of this particular subject. Mr. McCreery and his company are concerned more particularly with the future. They are doing pioneer work. The attitude of my company has been to collect and study all the evidence possible so far as present-day operating conditions are concerned. Our research has been along the lines of studying the effect of both types of tire on the trucks actually in operation today. Some of the questions that have been asked can be answered very successfully; others are far beyond most of us.

In respect to the road construction and the total permissible weight of the load, it has been said that trucks should be limited to approximately 10 or 12 tons on account of the investment in the roads today. I am inclined to differ from that belief. We should not establish low carrying-capacities today by reason of the limited progress thus far made in road construction. Years ago we were not content in railroad engineering to be limited by the weight of the ties, the rails, the bridges, and so on. We built larger and more powerful engines and strengthened the roadbed accordingly. Progress in road-building is essential if we are to make the most of motor truck transportation. I believe that, even at the sacrifice of millions of dollars in paved roads, we should, if necessary, wear them out, if by so doing we can establish the most economical unit of transportation. That is the goal to be worked for. Then we should build our roads accordingly.

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The first speaker cited the fact that the tire equipment of a whole fleet was changed from solid to pneumatic. In the symposium described in my paper, I fancy I received replies from as many fleet owners who stated they had not only changed once but changed back again to solid tires, because of the high operating expense and the many difficulties encountered. The figures and conclusions I arrived at, after making this analysis, are not merely the findings of our own development department, but are based on all the information I could get from those familiar with truck operation.

As to the figures of the so-called National Standard Truck Cost System, I wish that I could impress on this body the necessity for keeping accurate records of cost. It is only by this means that we shall make definite progress. The lack of information based on any cost system is amazing to me. For one cause or another the facts are almost never available except in a general way. I bespeak your strong support for the National Standard Truck Cost System, which is I believe the best one yet devised.

I am not in a position to state definitely the effect of improper tire inflation on the steering apparatus except to say that the less the tire is inflated the harder the vehicle steers and the more difficult it will be for that tire to stand up in service. There is no doubt that a properly inflated tire will bump and jar, but steering an underinflated tire is even more difficult.

Professor Berry asked how we know that less gasoline and less oil are used. Frankly, that comes back to the question of almost total absence of dependable data. In most cases, as far as I could tell, the facts sustained the contention that the pneumatic tire uses less gasoline and less oil on long hauls, but not on short hauls. Just as much gasoline is used in starting on solid as on pneumatic tires, and the oil consumption is increased by the added speed of the engine if we are to make use of the potential speed in the tires.

The answer I received in my symposium was that there was more wear in the bearings on pneumatic tires than on solid.

Larger tires are more easily cut by ruts, I think, because of the fact that there is a constant tendency of the tire to get out of the rut. The more rut wear the more the sidewalls of the tire are bound to be chafed. Under

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such conditions tire manufacturers have to strike a balance between ruggedness and durability, and flexibility and the distribution of heat.

E. A. HASKINS:—Regarding the small orifice in the ordinary tire valve, which is simply a continuation of the valve used in bicycle tires, it increases the time period for the inflation and it would be a great advantage to increase this tire-valve size. What has been done toward making a new kind of valve which will eliminate these difficulties?

JAMES E. HALE:—The problem of valves for inner tubes and tires is a difficult one. We have under test at present inner-tube valves which have three times the orifice area of the present passenger-car valves. It is fairly easy to make a valve any size desired, but a complication arises if the valve is made large; a threaded portion at the end is different from that of the standard valve. This invites trouble all over the country because the pump connections will not fit that portion.

If we could leave it to the valve-manufacturing company we might be tempted to do it, but the other companies are apt to treat it differently. A new valve has been designed very recently which seems worthy of thorough consideration. The tires and inner tubes are very well developed, but a number of auxiliaries are not worked out. The valve is one; the air-pump on motor trucks is another. Many things connected with rims are not completely developed. We are now trying to bring all accessories up to the same standard as the tires.

J. E. SCHIPPER:—On the large-size tires there is considerably more of a flat tread than on the smaller sizes; that is, the sidewall seems to be built up. Would that work out to advantage in the smaller-size tires, and has it any effect on the gas consumption on rutty roads?

MR. HALE:—There is a flat tread and steep sidewall on the 44 x 10 and 48 x 12-in. tires. In 1917 it was decided that we should make a 44 x 10-in. pneumatic truck tire with sufficient carrying capacity to support a 3-ton truck. The greatest difficulty encountered was to prevent separation between the tread and the carcass. The first tires were made with round treads, which caused the tires to flex considerably before the necessary contact area could be obtained. This flexing, com-

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bined with a component of the vertical load on the tire, resulted in a tremendous shearing action between the tread and carcass, which in time caused the tread to separate from the carcass or tire body. The logical thing was to make the tread flat, to give the necessary contact area without so much flexing and to widen it out, which would decrease the unit stress on the union between the tread and carcass of the tire. We did that and the results have been very satisfactory.

There seems to have been an understanding among tire designers that it is not good practice to have much of a shoulder at the edge of the tread of passenger-car tires. However, we have proved that a flat tread of the proper proportions has several distinct advantages and results in much longer tire life. As to the relative economy in gasoline consumption of the two types of tire on rutty roads, there would be a slight advantage in favor of the round tread; but when good roads are taken into consideration the advantage would be in favor of the flat tread.

J. W. SAFFOLD:—Referring to the six-wheel truck design, would it be flexible enough to stand up and be equal to the conventional truck? If so, will it furnish any more flexibility than the conventional design?

E. W. TEMPLIN:—To test the flexibility, we raised the forward wheels of the six-wheel truck 12 in. from the floor before we reached the limit of the universal connection. We also raised the rear wheels 12 in. We believe that 6 in. is enough for almost any condition. We have put that truck under a condition where diagonally opposite wheels were 18 in. lower than the other diagonally opposite wheels. In that condition the springs twisted, and from all appearances the rear springs were not stressed beyond anything reasonable. An authority on springs observed especially the condition of the stress of the springs, and his opinion was that it was perfectly satisfactory. In connection with the springs and the transmission, the four-wheel combination under the rear protects them to a great extent. Where the two-wheel construction bounces over the ruts in the road, the four-wheel combination will roll over them, and in that way is to some extent a protection.

MR. SAFFOLD:—Does this construction cut down the tendency to side-sway?

MR. TEMPLIN:—I believe it does. We made some short

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turns at high speed and the side-sway of that rear end was remarkably small in my estimation.

MR. SCHIPPER:—Will the load be concentrated on the rear set of wheels on these six-wheel trucks when the front set is raised?

MR. TEMPLIN:—When the power is applied in going forward, the forward tires are compressed and the rear tires are probably relieved under that condition. The torque momentarily applies an added load to the tires and that has a cushioning effect upon the driving mechanism.

M. D. SCOTT:—The question of whether self-locking differentials are practical was brought up about 18 months ago by a truck engineer. We purchased two trucks of exactly the same construction, except that one had a self-locking differential and the other was a standard truck. We ran those trucks over the Akron-Boston route, where we had been having considerable trouble with the worm-gear drive. It was very common to change a worm and wheel every 1000 to 5000 miles. After we had put these two trucks over the same route for some time, the self-locking differential was still on the original equipment, while on the truck with the standard differential we had made three changes of worm and wheel. In addition, we had made several changes in thrust bearings. The self-locking differential has now run 30,000 miles. At present we are using self-locking differentials on all long-distance hauling. It has a very material advantage in that respect; we have not tried it on different types of drive.

F. A. WHITTEN:—Could the truck be run without any differential?

MR. TEMPLIN:—We tried that out on this four-wheel combination and got into trouble. One of the shafts twisted off. I attribute this to the fact that we had no differential and a solid casting in the place of the differential. I am not in favor of going without a differential on a four-wheel combination; on a two-wheel combination it may work out.

MR. WHITTEN:—What special reasons are there for no-lock differentials and for locking differentials?

MR. SCOTT:—The principal reason for the locking differential is the high speed at which the trucks are driven. This can be explained by considering the number of times that a wheel leaves the ground in passing

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over obstructions or depressions. One wheel will leave the ground and, when it does, the wheel immediately starts to spin. When it comes back to the ground again, it must conform immediately to the speed of the opposite wheel and the strain all goes into the worm and wheel. There have been many reasons advanced for this, but the one advanced above seems to be the most logical.

MR. SAFFOLD:—The reasons for the locking differential are very good ones. One is that the ordinary differential is a compensating device and as such it is 100 per cent efficient. But as a differential it is not 100 per cent efficient. That is shown when the truck loses traction on one wheel because, when it spins, the power going through it is following the path of least resistance, and the vehicle is liable to be stalled. With the locking-type differential the power is equally applied to the two wheels. In this case it pulls out of the rut, instead of staying in; that is the chief difference. The second reason is that it prevents end skidding, if the skid starts from the differential. If that is stopped, the tendency toward skidding is prevented.

MR. HALE:—We have recently made some experiments and found that with the wheel not turning, the engine can turn two-thirds of a revolution. At the time of making these tests, we made tests which would show the side-sway permissible. There is a very pronounced lateral displacement possible without skidding the tires on the road surface, which is sufficient to account for the fact that the six-wheel trucks can turn corners and show very little skidding.

E. S. FOLJAMBE:—I was interested in the six-wheel truck a year ago. I believe that the ultimate heavy-haulage vehicle for city bus work will not be a six-wheel vehicle, but a semi-trailer-type combination having four wheels at the rear of the front vehicle, and four wheels at the rear of the semi-trailer. This can be operated by one man and would therefore be an economical proposition for bus work. There is the problem of whether it could be made to go around corners properly without differentials in the axles, and without in any way swiveling and pinioning. Experiment will ultimately show whether that can be done or not. Mr. Templin and I believe it should have the differential, but further tests will bring out these details. I know that all engineers are interested in this problem. I believe that the elec-

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trie traction lines will be replaced largely by the motor-truck bus-lines. The pneumatic tire will make that possible.

MR. WHITTEN:—The six-wheel truck is too new to offer criticism from the outside. The builders have not had time enough to know their own minds about what it will do. Possibly there are one or two things that have not been given the consideration they merit. We sell many trucks with pneumatic tires; more than 50 per cent are for use on bad roads. That is further borne out by the fact that many of the orders for pneumatic-equipped trucks specify not the standard gear ratio but one 25 per cent lower. The demand for pneumatic tires comes with a demand for a 12 to 1 gear ratio on 2-ton trucks.

Have any tests been made to determine what the trucks geared to run 30 m.p.h. with a large engine will do in city travel? Is this truck limited to one particular use?

Gasoline and oil-consumption comparisons hardly seem fair. The pneumatic records have been made on trucks with tires which have been developed for this purpose. The commercial solid tire has been made to sell. The efficiency varies tremendously. That may possibly be due to variations in tire manufacture. The tires used on electric trucks have to be made of an entirely different compound. So far as we have been able to determine, the highly efficient solid tire does not give any reduced mileage. Under equal conditions it gives better mileage. There is also a possibility for the development of the solid tire. We have run a few S.K. tires and have had remarkable results. That tire has great possibilities for city work.

In connection with pneumatic tires, the demand comes from people who want to put these tires out in the country where there are no good roads. They buy them because they cannot get there with the solid tires. But they soon find that operating trucks under those conditions is hard on the truck tires, engine and every other part of the chassis and body. That immediately brings about a demand for a good road, with a foundation and with good surface. With the ultimate road of that type, what sort of tire will be used? The trend toward the pneumatic tire may change in time because of the changed condition of the road surface. The locomotive with its steel track and steel wheels gets satisfactory running under most conditions. It will be a long time before we

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have the type of road which the railroad now has, but the smooth hard road appears to be the ultimate road. If that is the case, would not the solid tire serve well?

MR. SCOTT:—Regarding the 30 m.p.h. truck designed for pneumatic tires, its efficiency and the speed at which it must run in city streets, this is a question of the efficiency of the large engine in comparison with the small. Practically all of our experimental work has been over long runs. By using a 5-ton truck engine to draw a 3-ton load we found that this engine was more economical than that of the 3½-ton truck. This is because of the ease with which the large engine does the work. Over the mountains the smaller engine was working at a maximum. A very close check on that showed a 0.7-mile difference in gasoline consumption of the larger engine over the smaller.

City work is dependent upon the stops to be made. Many trucks stop often; with these we can get about 2 miles per gal. of gasoline. With that same truck outside of the city, we can get 6 miles per gal. An average on all the buses shows about 5 miles per gal. of gasoline with a 2-ton chassis. But that is not low mileage, because of the unusual number of starts and stops.

The same thing holds true with the larger or smaller-type engines. We use the larger-type engine on trucks for heavy grades. We found that the same things held true there when we used a 30-hp. engine. Our first trucks for such routes had 30-hp. engines, but they made no better mileage than the 45-hp. engines.

MR. HALE:—The efficiency of solid tires as far as absorbency is concerned depends entirely upon the formula used in compounding the rubber. It is possible to have a wide range in the efficiency of the rubber stock. There seems to be a very positive indication of a very satisfactory saving of gasoline in the use of the pneumatic as compared with solid tires. Many instances bear this out. The abstract reasons of just why this is so are probably very far-reaching and possibly we are not in a position to give them at present.

MR. FOLJAMBE:—In regard to the tendency toward or away from pneumatic tires when we get good roads, it seems that the tendency toward pneumatic tires will be increased under those conditions. With good roads, speeding is the next thing desired. Even on good roads the desired speed cannot be attained with a solid tire.

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There never will be a time when all roads will be improved. Even with a highly-improved highway system the truck must occasionally leave the hard surface, which again requires some kind of tire other than a solid one.

MR. HALE:—The speed at which the pneumatic-tired trucks shall be operated must be controlled entirely by the safety at which they can be operated. We have found that 25 to 30 m.p.h. is satisfactory; it is very similar to passenger-car speed.

R. HUFF:—Regarding the six-wheel truck construction suggestion, I have had some experience with pneumatic tires on small 1-ton trucks. It is customary with most manufacturers of 1-ton trucks to use the standard touring-car track, namely 56 in. from center to center of the tires. My experience has been that the use of pneumatic tires on these trucks raises the center of gravity of the load so high that there is a serious tendency for the truck to tip over when making sharp turns rapidly or on highly crowned roads. A lower center of gravity which might be obtained by a six-wheel truck construction would be an advantage in this respect. In the case of heavier trucks, the six-wheel type would hold the advantage that, in cases of changing tires, it would be easier for a driver working alone to change the smaller tire required than is the case now where he is obliged to change one of the extremely large-sized tires.

In connection with the use of pneumatic tires on trucks, what type and what capacity of jack have been found to be most satisfactory? My own experience with jacks in general, when used on pneumatic-tired trucks, has been most unsatisfactory. An overload with a flat tire is extremely hard to handle. I find it very difficult to get a jack which is low enough to go under the axle in this case and still have range of lift sufficient to raise the axle high enough to permit handling the tire. How far can a man drive an overloaded truck with a flat tire without ruining the casing? I ask this because I have had experience with drivers who brought in brand-new casings that were absolutely ruined, although they had been driven only a few miles. In this case the drivers claim that they found the tire flat and did not know it was flat until they had driven some distance.

Regarding the discussion that a high gear ratio and a large engine should be used with pneumatic-tired trucks, experience has demonstrated that a high gear ratio is not

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desirable in trucks which are running exclusively in cities and much of the time in thick traffic. Many of the cities have ordinances limiting the speeds of 3 to 5-ton trucks to 10, 12 and 15 m.p.h. A driver is automatically limited when in traffic to a speed sometimes lower than this, and he would be obliged to run in intermediate or low gear most of the time in city work if his truck were equipped with the proposed high gear ratio. It therefore seems to me that it will always be necessary for manufacturers to build two different types of chassis, one with the high gear ratio and large engine for pneumatic-tired trucks for cross-country work and another with a low gear ratio and small engine for solid-tired trucks and pneumatic-tired trucks to be used exclusively on short hauls in city traffic.

There has been considerable talk to the effect that the pneumatic-tire equipment for trucks would completely supersede solid-tire equipment, with the claim that the pneumatic tire rides so much easier that the truck chassis will stand up better than it would in the case of the solid tires. No doubt this is true in the country when driving at high speeds, but it has been my experience that heavy trucks in crowded city traffic on short hauls last practically indefinitely when run on solid tires, because the nature of the service and the traffic conditions prevent the truck from running fast enough to develop any serious vibration. I feel that there will always be a large field for solid tires for heavy trucks in city work.

MR. SCOTT:—We use two jacks, one large and one small. One jack alone has not enough lift to take the tire off the ground; it simply takes most of the weight off the tire. After that we use another jack. Some jacks are all right for small trucks, but the 3½ and 5-ton trucks are another problem.

W. E. SHIVELY:—To get out of a mud-hole in case a tire becomes flat it is not necessary to drive very far. At low speed the tire would stand that amount of running without any harmful effects. There is a tremendous strain on the tire, but the speed has much to do with that. The only harmful effect would be in case the driver did not know when the tire went flat. I believe that is not a very serious objection.

MR. TEMPLIN:—In regard to the gear ratios given in the paper, we had to take trucks under average conditions. For use within city limits, I would myself design buses

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with gear ratios corresponding to the present practice with solid tires. On buses operated between Akron and Cleveland I would put the extremely low gear ratios, such as 5 to 1, because 90 per cent of the mileage would be at such ratios. There would be only about 10 per cent on the high ratio.

MR. SCAIFE:—Like many others, when the six-wheel vehicle was first presented, I considered it a freak. We have a tendency to be rather skeptical of the practical application of the vehicle. I believe there will be a field for that vehicle. Bus lines will be looked forward to, to replace the street-car of the present day in large measure, and there will be a field where a vehicle of this kind will be very valuable in solving some transportation problems. The four-wheel vehicle will have a large place in transportation for some time to come.

E. T. BIRDSALL:—It appears to me that one of the first things to be done is to redesign the engines. When the Akron-Boston express route was first started, I noticed that almost the first thing they did was to put a 5-ton truck engine in a 3-ton truck, to get the necessary high speed. Truck manufacturers all seem to have an antipathy to an engine that runs over 900 r.p.m. With this limitation the engine designer has a hopeless task. We must get away from the ordinary truck engine. It is possible, feasible and practical to build a truck engine that will run normally at 2500 r.p.m. and this will obviate many troubles with gear ratios, because the engine will run at high efficiency at low truck speeds in the city, as well as at high speed in the country. The pneumatic truck tire will, I believe, force the truck manufacturer to use that type of engine. It will cost more than the ordinary engine, but it will work at a higher efficiency. We cannot do it all at once. The main consideration seems to be a pneumatic-tired truck making long hauls, doing a large percentage of high-speed and high-gear work and a small percentage of the intermediate and low-speed work. There will be customers who will want to do other things under other conditions, and the type of engine I mention is the only one that will give satisfaction in such cases. It is very difficult, however, to get the truck and engine manufacturers to take so large a step at once.

F. A. SEIBERLING:—Are the things we have been talking about actualities or dreams? Has this six-wheel

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truck any merit? I was hoping that Mr. Templin would stand for the extreme idea. He said he was willing to admit that the differential ought to come in. When I think, for instance, of the 5-ton truck running on a smooth pavement, I contend that the six-wheel truck, as we have developed it here, without the differential, has a place. Am I right or wrong?

S. G. THOMPSON:—There is nothing new in the use of six wheels with tandem rear drive as produced here. The experiment has been made several times in the past 20 years. There is much to consider in connection with Mr. Seiberling's remarks regarding bus-line development, and whether there will be a trend toward pneumatic tires that will ultimately resolve itself into an economic proposition. In discussing the general use of pneumatic tires for heavy motor trucks, it must be remembered that their principal advantage is higher average speeds. Whether this higher speed is generally obtainable to the extent of resulting in an increase in the value of the service rendered is another question which is subject to speculation, especially if we consider that, at best, freight movement by motor truck is largely confined to city areas and inter-city hauling is limited to a small percentage of the gross railroad tonnage of the country. For example, low-rate freight comprising the products of mines, agriculture annuals and forests represents 77 per cent of the total tonnage of the railroads, and moves average distances of from 133 to 335 miles. High-rate freight comprising the products of manufacturing and merchandising is only 23 per cent of the total tonnage and moves but a comparatively short distance, as is shown by the fact that the average freight haul for all classes of commodities is only 167 miles and but 138 miles in the Eastern district. These statistics lead me to believe that inter-city motor-truck hauling is apt to be limited to distances where perhaps the "value in service" of large pneumatic tires will be difficult to establish.

MR. BIRDSALL:—I see great possibilities for the development of this six-wheel truck. My original business was operating a street railway in a certain city, so I can state the comparative advantages of the bus over the street railway. The initial investment for a street railway is extremely high. A number of street railways have gone out of business recently. One company has

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taken down all its trolley wire and poles and sold them. On two roads that I had built, they had a strike and went out of business. I believe that the tracks in the streets of congested districts must be eliminated.

H. B. KNAP:—On trucks in general it appears that solid tires will be used in cities for short-haul hard-road low-speed work. Pneumatic tires will be used for high-speed long-haul conditions and for soft-road rough-country conditions. In other words, the added expense per mile of the pneumatic tire must be offset chiefly by making more trips per year, either by virtue of higher permissible speeds or by being able to negotiate soft roads and ground where solid-tire equipment cannot operate.

If the manufacturer builds more pneumatic-tired trucks than there is a correct market for, he runs the risk of having some of them sold where solid-tire equipment would be preferable, which would be a set-back for the use of pneumatic-tire equipment. It is therefore believed that the production requirements should be very carefully estimated, and that the selling of pneumatic tires should be closely supervised. In this connection the lowering of the solid-pneumatic price differential would be of great help in the education of truck operators.

As to cushion tires, it seems that some of them are about half-way between solid and pneumatic tires in resiliency, and therefore do not have so much effect on permissible speeds, or on traction in soft going.

L. P. KALB:—Many engineers connected with the motor-truck industry are beginning to realize the broadening effect that pneumatic tires will have upon the truck field. It would, therefore, be foolish for anyone to oppose this trend. The six-wheel truck may have shown us the way to overcome what was formerly considered one of the greatest drawbacks to large-sized pneumatic-tired trucks. It has shown that the solution of the problem is not impossible. However, we must forget our solid-tire prejudices if the pneumatic tire is to be used to the fullest advantage. We must start with a clean slate and develop things along different lines. Whether it will be a six or a four-wheel truck, I hesitate to state. It will require much development and those who go into it early will reap the fruit, while those who lag will suffer.

J. A. KRAUS:—Prospective buyers of motor trucks, not having had previous experience with motor vehicles, naturally expect that the solid tire will give 50,000 miles

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and feel they are getting something better in the solid tire. The various designs of cushion wheels are an answer to the shortcomings of the solid tire.

The discussion indicates that most trucks are operated in large cities where there is solid pavement. We have an increasing demand for trucks for use in foreign countries. This demand is at present very great. It is surprising that in Africa, Australia, Java and other places they are asking for pneumatic tires. We have received an order for 300 trucks to be equipped with front and rear pneumatic tires. Certainly the purchasers knew what they wanted. We have had enough experience with pneumatic tires to draw a comparison. Experience with solid tires has shown that very frequently the chassis, especially the engine, suffers greatly from shocks; the vibration is considerable. A certain model was produced and equipped with pneumatic front tires; a square gasoline tank was used. Later, a revision of this model brought out solid tires on the front. The pneumatic-tired models gave good service, nearly 100 per cent, but the gasoline tanks on the solid-tired trucks had to be replaced.

Relative to the multi-wheel vehicle, we should not give much consideration to semi-trailers. Many overlook the danger with these when turning corners on down grades, and applying the brakes at the same time. They will fold up like a jack-knife. With the short tractor with a two-wheel trailer, when turning corners on a wet street, the back end comes around too fast and results in loss of control of the steering. The semi-trailer has convinced me that the multi-wheel truck of the future will be of the type that the Goodyear company has developed. It must be admitted that the smaller size of wheel and the reduced weight of the tire will prove a great benefit to owners and drivers.

MR. THOMPSON:—The field for heavy-duty pneumatic-tire trucks appears to be very limited. The best argument I can find for the solid tire is contained in the papers that have been presented. In Mr. McCreery's paper we find what purports to be a table of comparative performance, in which several units are considered. To me this table appears to be simply a statement of results obtained under certain operating conditions, controlled by certain factors. It does not appear that this is a comparative analysis in any way, for the reason that for each investigation all of the factors were changed. If an in-

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vestigation is being conducted to determine the results to be obtained by the use of one device in comparison with the use of another device designed for the same work, the only factors which should change are the factors controlled by the device. To change the tire factor and leave all other factors the same would give comparable conditions.

An operating-cost table that has been recently compiled shows that the cost per ton-mile for the pneumatic tire is $0.1055, while the cost for the solid tire is $0.1123. However, if we examine the items which are included in these costs, we find that in the case of the pneumatic-tired truck depreciation is based upon approximately a 20-year life, while in the case of the solid tire depreciation is based on what is known today to be the established life of a truck operating under those conditions. In view of the fact that 68 per cent of the truck manufacturers have been in business less than five years, how can the depreciation be based upon a 20-year life? As we have not enough evidence in the industry today to support the claim for a 20-year life, it would seem to me to be advisable to eliminate the depreciation charge. If depreciation is omitted, or if amortization is placed at a definite period, the saving shown disappears entirely; so it would appear that the table is merely a selection of the bookkeeping methods to prove the case.

Let me call attention also to the item of interest which I notice in the cost tables and which should not appear as an item of operating expense. The only reason that motor trucks are used is because they have an earning value. They are more economical than other means of transportation. The sole reason for making an investment in a motor truck is to avail oneself of its earning value. Consequently the earning value of the investment is the reason for the investment and that in itself constitutes the interest. If the earning value was not sufficient to earn the same amount of interest that the money might earn when placed in sound securities, there would be no reason for making the investment. Consequently interest is not an operating expense. This is something the motor-truck industry should consider.

G. J. THOMAS:—The multi-axles on the six-wheel truck are well worth developing. Being a four-wheel-drive engineer, I might say that the four-wheel drive has really never been fully developed. We must distribute the weight more evenly and reduce the entire load. The only

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way is to distribute the load over a large number of wheels.

This six-wheel truck is very similar to a truck we built some six years ago, but the truck we built had a six-wheel drive. It was a dream of a lumber man who bought a four-wheel drive and had to pull it out of a mud-hole with ox teams. This truck has been run for six years steadily in the logging business, carrying logs. It was built with steel tires all around and has been very successful. I believe it proves that the Goodyear company is on the right track. I think that within five years trackless street-cars will be built with eight drivers. I believe that is possible, more especially since I have seen the demonstration of the six-wheel-drive truck in Akron.

L. M. BAKER:—Regarding the six-wheel-drive truck, I admit that I have had a more comfortable ride in one on a solid board than I have had in many touring cars with spring seats. It strikes me as being a very good thing for work up and down the street as a bus. For pulling in and out of foundation holes, hauling contractors' supplies and other heavy truck jobs, I think it would not do so well because of the fixed condition of the two rear axles. It struck me after I had seen it that this truck would to a certain extent replace the street car.

MR. DARROW:—The question of solid and pneumatic tires can be argued only on two counts. The first is reliability. We can expect 7000 miles and over from pneumatic tires. During the life of each tire we can expect to remove it once from necessity, and perhaps other times for treatment. With average mileage and care we must remove one tire per month.

The second point is cost. The first-class improved highway of concrete, with a deep foundation, costs $40,000 per mile. Mr. Seiberling mentioned that there are 200,000 miles of more-or-less improved highways in the United States. This runs up to $8,000,000,000. If we ever get highways of that character, the element of depreciation on roads must be included in the cost of pneumatic tires.

In regard to unit load, there is a limit to the weight that can be carried on solid tires per inch of tire width. As a matter of fact, this is not the right way to measure it; it should be pounds per square inch of contact area. With pneumatic tires, the load per each square inch of contact area is equal to the inflation pressure. As to the

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cushioning, a solid tire deflects about ⅜ in. A pneumatic tire deflects ¾ in. or more. We have only one-quarter the impact with one-half the load, per square inch. Those things have a bearing on the maintenance of the foundation of the road. The road is the expensive part. We must keep in mind that solid tires will injure the foundation of the road and that the investment involved in keeping the roads in repair is tremendous.

To sum up and connect three things together, in a pneumatic-tired truck we have a saving in the truck itself, an increased efficiency and a large saving in roads. Taking into consideration only the initial tire cost and mileage delivered, we cannot show that pneumatic tires are more economical but, considering these other things, there is no question that pneumatic tires excel solid ones.

JOSEPH SCHAEFFERS:—Considering the future prospects of large-size pneumatic tires, it appears that the weight will prove the main limiting factor. A driver and his helper can handle a tire with rim below 200 lb., so that the 40 x 8-in. tire would still be practical, while the 48 x 12-in. tire, weighing with rim about 500 lb., can hardly be handled by one or two men without involving undue effort. In exceptional cases the very large sizes may be justified and establish a field of usefulness, but for general adoption they appear to be too heavy and too expensive.

The question of rim equipment on pneumatic-tired trucks is merely a question of efficiency against convenience. The detachable rim equipment is lighter; it is therefore more efficient and results in longer tire life. On a passenger car, the greater convenience for the owner-driver in having an inflated tire on the demountable rim is worth the extra cost. But as Mr. Darrow pointed out, the tires are good for at least 7000 miles and one need not figure on more than one change of tire per month. What is the difference in weight between the detachable and the demountable equipment? How much does that difference in unsprung weight affect the tire life? Is it worth while to save possibly 15 min. once a month for the driver, at the expense of lower efficiency for every ton-mile?

The distribution of the main load over four rear tires as accomplished in the tandem rear axle is certainly worth a very thorough test. In July, 1911, at the Dayton S. A. E. meeting, Mr. Reeves demonstrated an eight-

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wheel passenger-car. It was an easy-riding car, but the economic necessity was not there, certainly not to the same extent as at this time for commercial vehicles.

It is impossible to judge, at this stage, to what extent the tire life will be affected by the fixed position of all four driving-wheels. If the wheelbase is long enough and the drive-wheels set as closely together as possible, the extra tire wear may be negligible. Only tests covering several ten thousands of miles on a comparative basis can demonstrate this. Just because six-wheel trucks were not successful years ago, it does not follow that

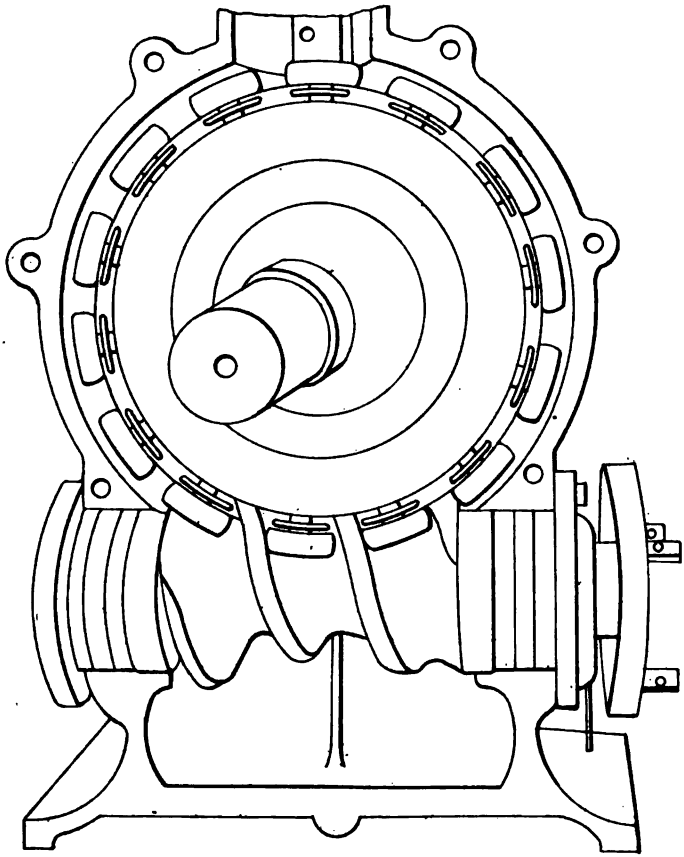

FIG. 17—THE PEKRUN DRIVE

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they will not be successful. E. R. Hewitt built an eight-cylinder V-type engined passenger car some 12 years ago. The fact that he abandoned that design does not prevent the present V-type eight-cylinder car from being a success.

In reference to the design of tandem rear axles, it seems that the worm drive would here be even less appropriate on account of the much wider range in speeds. The worm drive, if used, should of course have a proper amount of bearing surface between the worm and the wheel. Shock loads, as well as a continuous application of maximum loads, break up the oil film between worm and gear and cause metal-to-metal contact with incidental wear and destruction, as was evidenced by the worm gear with standard gear differential, mentioned by Mr. Scott. The only worm gear drive which provides rolling contact between worm and gear is the Pekrun drive, shown in Fig. 17. However, a tandem rear axle gives an excellent opportunity for chain drive, using two dead axles of I-beam section, made of high-grade alloy steel, and a high-speed jackshaft between the axles but supported above the springs. By a judicious use of the newer light metals such as duralumin or electron, the weight of hubs, wheels and rims can be cut down to about one-third of the present weight. The total unsprung weight of such a design would be only a small fraction of the weight given in Mr. Templin's paper.

The jackshaft bevel drive should be used if possible with a double transmission arrangement, one high-speed direct for country roads and one low-speed direct for city traffic and for bad roads, with about 30 to 35 per cent difference between the two, and giving a choice of six speeds with a three-speed gearset. A straight-line drive should be used, eliminating power losses in universal-joints. The running of such a tandem axle and a single-drive-axle for some 50,000 miles on a comparative basis should tell an interesting story. The jackshaft should by all means carry a self-locking differential.

MR. WHITTEN:—I asked one of our dealers about his trucks and if he was doing any cross-country hauling. He said he had come to buy two more trucks for 80-mile long-distance hauling. I asked if he intended to have pneumatic tires on these trucks, and he told me he had no use for the pneumatic tire; that there was a new State highway on the entire route, that he had no trouble in making the 160 miles per day on solid tires and that he

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felt he gained nothing by using pneumatic tires. That led me to bring up this question of roads.

L. C. ROCKHILL:—I am apt to look at this problem from a merchandising rather than an engineering standpoint. If a thing is needed from the standpoint of public service, the engineering fraternity works the thing out. However, I think that sometimes we confuse the issue in discussing the virtues of pneumatic and solid tires on large trucks, by thinking too much about what is past and not enough about the future. I have never been able to enthuse very much over the possibility of using pneumatic tires on such trucks as have been used with solid tires for years past, or over the truck market as it has been in the past. The thing that interests me primarily is the possible truck market in the future. I think that there are tremendous possibilities for the use of large trucks in new fields of endeavor and that they are almost solely dependent upon the use of pneumatic tires. Something must be done to make the large trucks more useful in filling our transportation needs. Large trucks have run on pneumatic tires from Akron to Boston during a period of more than three years. I suppose that those trucks are not particularly economical in that service and I am not arguing that we will ever run large trucks over a 1500-mile route, but it is indicated that things can be done with a large pneumatic-tired truck that cannot be done with a solid-tired truck. We tried sending solid-tired trucks to carry some cargoes to Philadelphia from Akron. We wanted to get a comparison with our pneumatic-tired truck units. The driver made one trip and quit. We could not have hired him to make another trip at any price.

S. B. LAMBERT:—What troubles have been experienced with air-pumps, as to oiling, dirt and heating of the pump? One that pumps to a pressure of 100 lb. per sq. in. is apt to get hot. Has anyone had trouble in getting the right pressure for large tires?

MR. SCOTT:—In a general way, the trouble with pumps has been that they get hot and will not function. The bearing burns out. The pump manufacturers have had to use the very greatest skill in making an air-cooled pump that is fool-proof. Naturally, the air-pump receives very little attention. The pump manufacturers have changed their models repeatedly and now have something that they consider satisfactory.

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Another problem is how the pump should be attached to the car. This has been worked out by having a connection which is standardized to a greater or less extent on the transmission.

A TRACTOR ENGINE TEST

By C A Norman[1] and B Stockfleth[2]

A four-cylinder 4 by 5-in. truck and tractor engine, designed for either kerosene or gasoline fuel and having the very low volumetric compression ratio of 3.36, was used. Only by suitable adjustments was it found possible to make it show a fuel consumption as low as 0.67 lb. per b.hp.-hr.; but with a slight variation in power and only a different carbureter adjustment the fuel consumption at 600 r.p.m. increased to about 1.2 lb., or 70 per cent, emphasizing the importance of knowing what constitutes the best engine adjustment and of disseminating such knowledge. The engine and its dimensions, the experimental apparatus and the method of testing are fully described and discussed, the results being presented in charts showing performance curves. These are described, analyzed and the results interpreted.

The tests published here were carried out with an engine of lower speed and of lower compression ratio than those used by Professor Berry in the tests reported before this Society and elsewhere. More factors are covered; notably jacket loss, exhaust temperature, cooling through the carbureter, vacuum in the inlet manifold, etc. Attempts were made to take indicator diagrams and, at lower speeds, some interesting information was obtained. As the indicator used proved unreliable at higher speeds, this phase of the experiments will not be referred to here.

The engine used, which is shown in Fig. 1, was a four-cylinder 4 by 5-in. truck and tractor engine intended to run on kerosene as well as on gasoline, and therefore had the very low volumetric compression ratio of 3.36. It had been in use in the field and at the factory for experi-

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[2] Chief engineer of experimental laboratory No. 5, International Harvester Co., Chicago.

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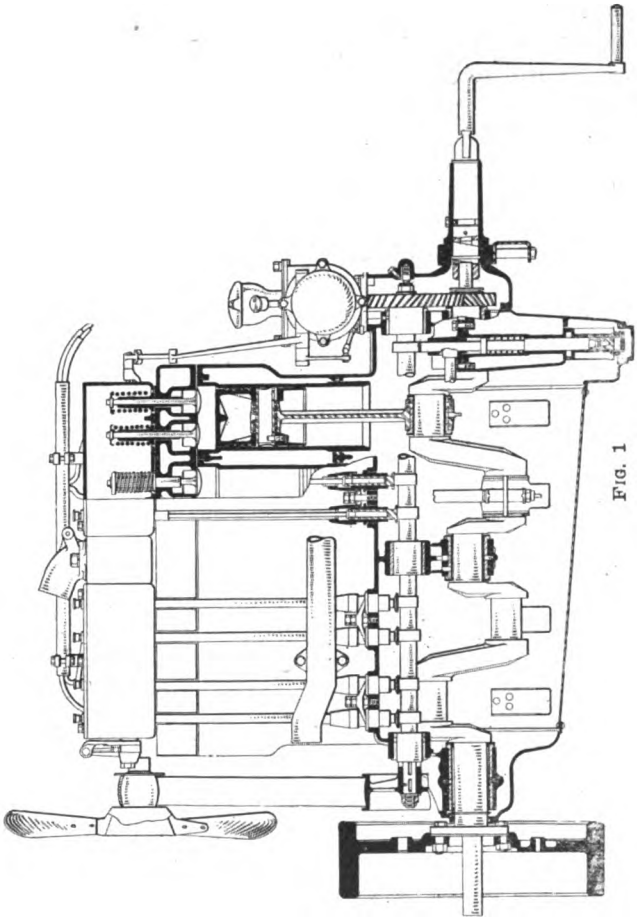

FIG. 1

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mental purposes for over 2 years and, apart from a thorough cleaning and valve grinding, received no special treatment for these tests. It was found possible only by suitable adjustments to make it show a fuel consumption as low as 0.67 lb. per b. hp.-hr. However, with hardly any variation in power and only by a different carbureter adjustment, the fuel consumption at 600 r.p.m. increased to approximately 1.2 lb., an increase of 70 per cent. This would seem to demonstrate strikingly the importance of knowing what constitutes the best adjustment for an engine and of disseminating such knowledge among the engine using public.

The inlet valve had a 0.225-in. lift, while the lift of the exhaust valve was 0.285 in. Both valves had the same opening, 1⅝ in. On an average the inlet valve opens at 12 deg. after the dead center and closes at 40 deg. after the dead center. The exhaust valve opens 49 deg. before the dead center and closes 11 deg. after the dead center. The fuel used in the series of tests was Red Crown gasoline with a specific gravity of 0.733, a sample fractional distillation of which is shown below.

100 CC. SAMPLE USED IN DISTILLATION

cc.	Temperature, deg. fahr.	Check Temperature, deg. fahr.	Westphal Specific Gravity	cc.	Temperature, deg. fahr.	Check Temperature, deg. fahr.	Westphal Specific Gravity
5	156	152	.....	55	276	271	....
10	173	169	.....	60	290	284	0.746
15	187	180	0.679	65	305	294	....
20	194	194	.....	70	317	308	....
25	204	205	.....	75	332	320	0.766
30	214	216	0.703	80	348	339	....
35	230	228	.....	85	367	354	....
40	239	239	.....	90	399	387	0.789
45	253	249	0.728	92	408	.....	....
50	266	262		Loss—6.5 cc. Residue—1.5 cc.			

The higher heating value of this fuel was 19,288 B.t.u. per lb., giving a lower heating value of about 18,000 B.t.u. per lb.

The general arrangement of experimental apparatus is shown in Fig. 2. The air in passing to the engine first enters an equalizing tank of about 17-cu. ft. capacity, through a 2-in. sharp-edged orifice specially calibrated against a standard gas meter from the Peoples Gas,

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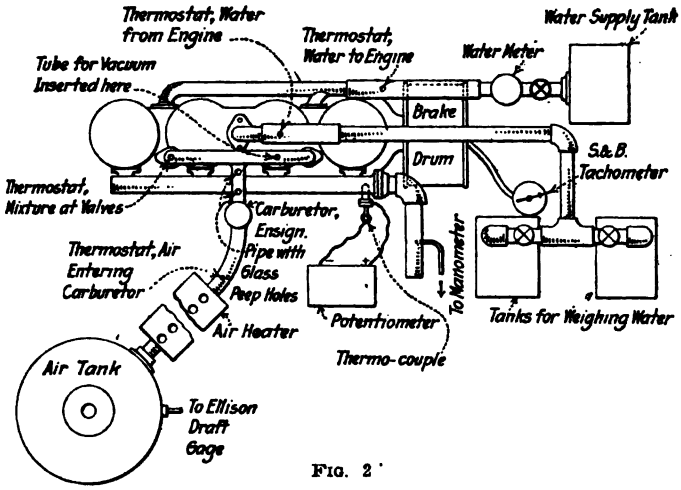

FIG. 2

Light & Coke Co. The vacuum in the tank, which is equal to the pressure drop through the orifice, was measured by an Ellison draft gage. From the tank the air passes through a pipe heated by gas flames under a hood. The temperature of the air entering the carbureter was measured by a bare bulb thermometer. An Ensign type JK carbureter, of 1¼-in. nominal size, was used. This was connected to the intake manifold by a short pipe, with glass peep-holes.

The temperature in the inlet manifold was measured by a bare bulb thermometer and the vacuum in the manifold by a U-tube, using water as a liquid. Cooling water was supplied from a constant-pressure tank, and after passing through the jackets was delivered to two weighing tanks on the scales. The inlet and outlet temperatures of the cooling water were measured by bare bulb thermometers. The temperatures were held practically constant by controlling the water flow by a valve. All the thermometers were calibrated against a thermometer certified by the Bureau of Standards. The temperature of the exhaust was taken by a Leeds & Northrup recording instrument, using a base-metal thermocouple.

The indicator drive was taken off the magneto shaft as best illustrated on the photograph shown in Fig. 3. The power was absorbed by a prony brake.

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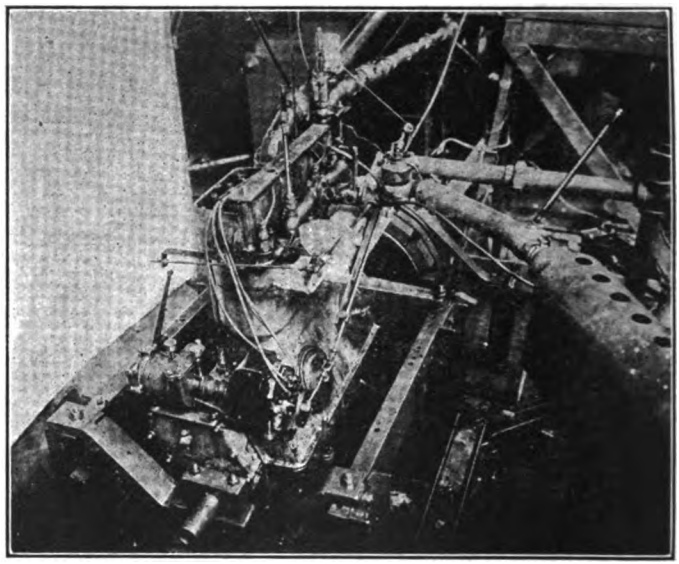

FIG. 3

METHOD OF TESTING

The engine was run as far as possible at a series of set speeds with the throttle locked in a wide-open position, except at 300 r.p.m. where slight throttling was necessary. At each engine speed, 300, 400, 500, etc., r.p.m., the temperature of the air to the carbureter was held successively at certain fixed temperatures, usually 70, 85, 100, 120, 160, 200 and 240 deg. fahr.

After the establishment of the desired temperature, the carbureter was set first for the maximum richness of mixture at which the engine would run satisfactorily, then for the minimum richness. Thereafter, five or more intermediate settings were used. Every carbureter setting was held for 30 min. and readings taken every 5 min. At least 49 half-hour runs were thus made at each speed. The engine was cleaned and the valves touched up after the completion of the series of runs at each speed to maintain it in an unchanged condition and thus make certain of truly comparable results.

In Figs. 4 to 11 inclusive are given eight sets of curves showing for each speed the influence of the richness of the mixture and of the air temperature on the power

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developed. The same influence on fuel economy is shown for the two speeds in Figs 12 and 13. At lower speeds the power, as will be seen, is influenced very little by variation of richness, between rather wide limits. Up to 400 r.p.m., practically no variation appears throughout the whole range of workable mixtures. At 500 r.p.m. it is possible to operate the engine on mixtures of less than 8 lb. of air per lb. of fuel, though at a very marked sacrifice of power. From 9.5 lb. up to over 17 lb. the power, however, remains practically constant.

At 600 r.p.m. a drop in power is noticeable with air quantities exceeding 14 to 15 lb. per lb. of fuel. At higher speeds the range of constant and optimum power becomes ever narrower until at 900 and 1000 r.p.m. there is a decided peak at about 10.5 to 11 lb. of air per lb. of fuel.

This behavior is probably best explained by the greater ignitability and more rapid progress of combustion of the over-rich mixtures. Theoretically, 1 lb. of fuel requires for complete combustion slightly less than 15 lb. of air. This mixture, however, is not so readily ignitable as the richer mixtures. This seems to be further indicated by the fact that the amount of heat dissipated into cooling water, as well as the temperature of the exhaust, increases quite regularly up to 13 to 15 lb. of air. The greater heat dissipation is probably due to longer-sustained high temperatures, as combustion continues

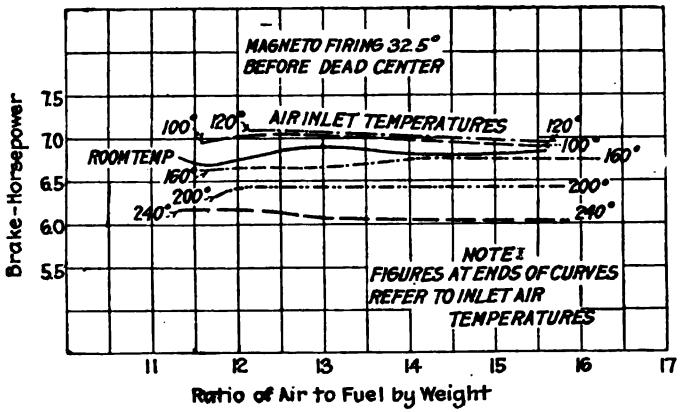

FIG. 4

Speed 800 r.p.m.

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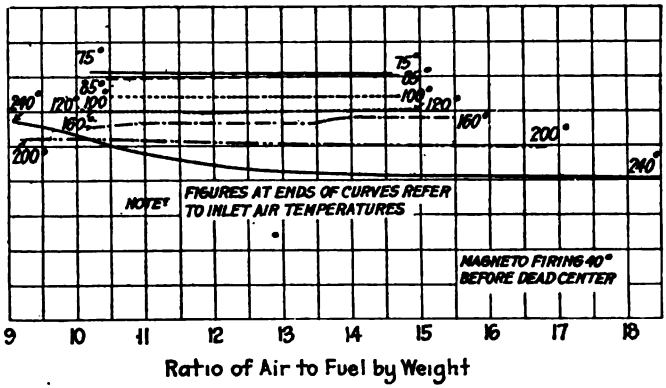

FIG. 5
Speed 400 r.p.m.

through the whole expansion stroke, giving a greater heat flow to the walls and perhaps even partial after-burning in the exhaust. If these values were plotted the drop of the curves, which is especially apparent in the curve for the exhaust temperature at air quantities over 15 lb., is due no doubt to lower temperatures generally, on account of air excess and less heat produced by combustion.

The influence of increased richness of mixture on fuel economy is uniformly toward a greater fuel consumption. This is only natural, as part of the fuel must go through unburnt or burnt to carbon monoxide. (See Table 1,

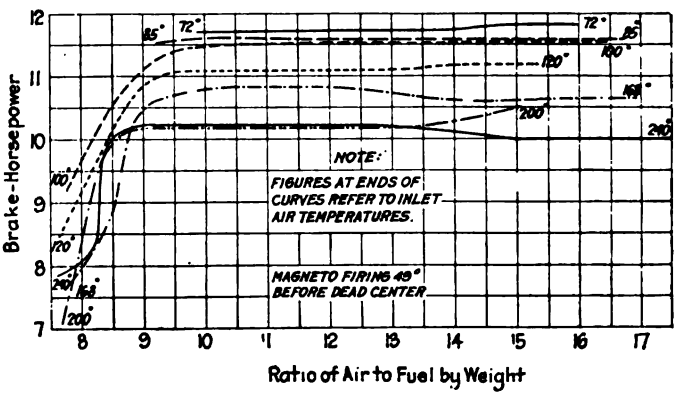

FIG. 6
Speed 500 r.p.m.

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TABLE 1

Speed, r.p.m.	Air Inlet Temperature, 70 deg. fahr.						Air Inlet Temperature, 240 deg. fahr.					
	Mixture Ratio of Air to Fuel by Weight	Percentage of		Mixture Ratio of Air to Fuel by Weight	Percentage of		Mixture Ratio of Air to Fuel by Weight	Percentage of		Mixture Ratio of Air to Fuel by Weight	Percentage of	
		CO_2	CO		CO_2	CO		CO_2	CO		CO_2	CO
300	.....	....	....	.....	....	....	15.85	8.5	4.5	11.31	4.2	9.5
400	15.09	11.0	1.2	10.68	5.8	7.7	18.99	6.8	0.3	9.53	4.3	10.6
500	15.96	9.4	0.3	9.85	5.0	8.0	17.44	4.8	0.4	7.58	0.3	*1.0
600	15.89	7.3	0.1	7.50	3.0	8.0	16.88	9.7	0.2	7.07	2.0	9.6
700	15.98	2.0	*0.3	7.65	2.3	8.4	17.79	6.3	0.4	7.37	1.7	8.0
800	13.90	7.7	3.4	6.83	3.2	11.9	18.39	5.3	1.0	6.86	3.8	11.2
900	13.78	9.5	2.8	7.65	4.2	11.5	18.59	8.4	0.3	6.78	2.6	10.4
1 000	15.60	7.3	1.4	7.02	3.8	12.1	19.54	6.4	0.5	6.54	2.4	9.5

*Sample diluted with air, due to leakage of stop-cock on sample can.

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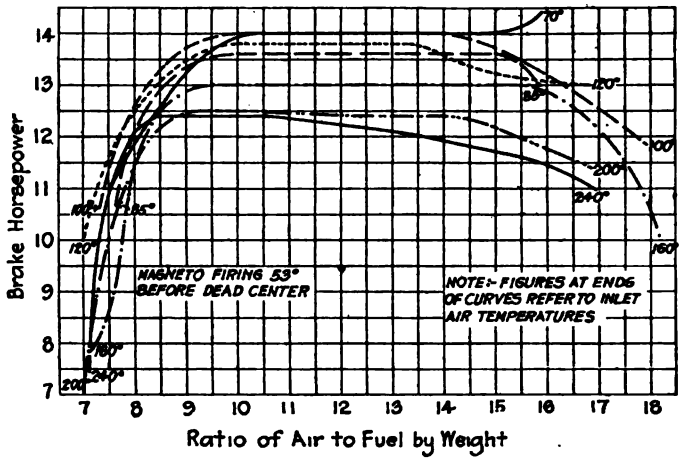
Brake Horsepower
Ratio of Air to Fuel by Weight
MAGNETO FIRING 53° BEFORE DEAD CENTER
NOTE:- FIGURES AT ENDS OF CURVES REFER TO INLET AIR TEMPERATURES

FIG. 7
Speed 600 r.p.m.

which gives some very rough determinations in this respect.)

At 900 and 1000 r.p.m., very lean mixtures likewise show an increase in the fuel consumption per brake horse-

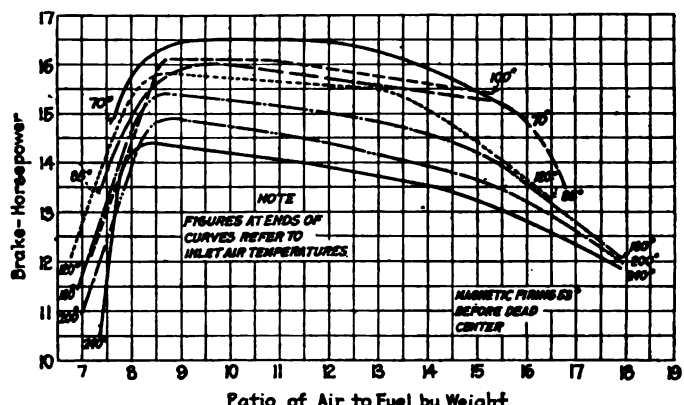
Brake-Horsepower
Ratio of Air to Fuel by Weight
NOTE
FIGURES AT ENDS OF CURVES REFER TO INLET AIR TEMPERATURES.
MAGNETIC FIRING 53° BEFORE DEAD CENTER

FIG. 8
Speed 700 r.p.m.

power due to a low power development with the combustion too slow for the speeds. This increase, however, is slight and should not be dwelt upon to the engine using

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public. Over-richness is the great source of fuel waste and should be preached against.

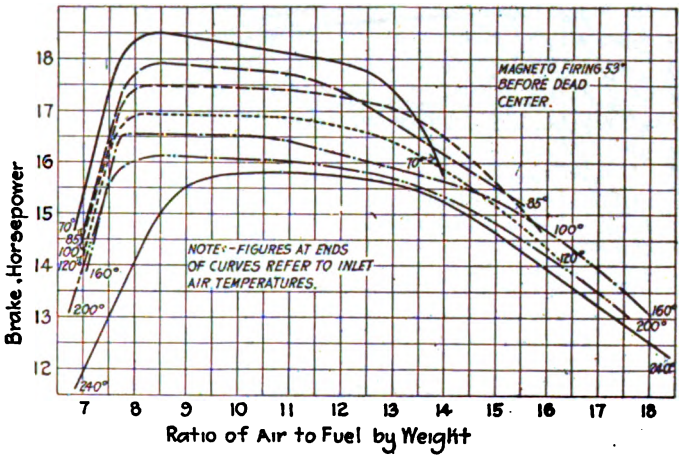

FIG. 9
Speed 800 r.p.m.

The general effect of air heating as shown by the curves in Figs. 4 to 11 is to reduce power. The amount of this reduction from the maximum to the minimum

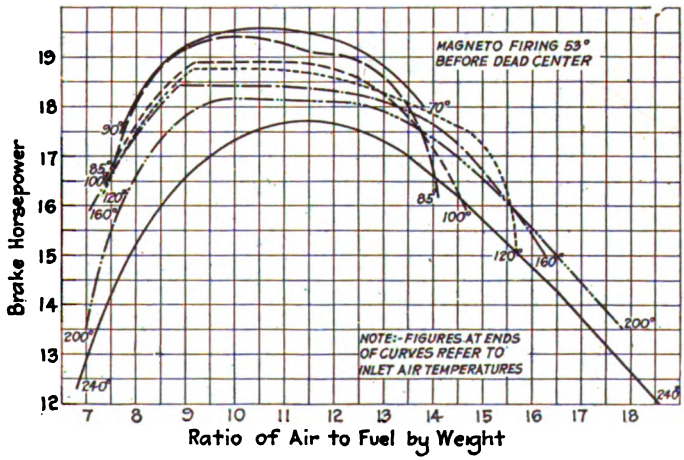

FIG. 10
Speed 900 r.p.m.

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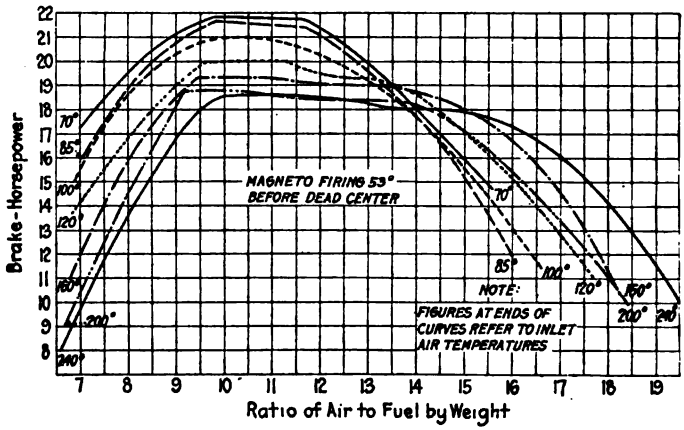

FIG. 11

Speed 1000 r.p.m.

performance at some selected air to fuel ratios is shown in Table 2 and varies from 5.48 per cent, at 800 r.p.m. and the 15 to 1 ratio, to 15.7 per cent, at 400 r.p.m. and the

TABLE 2

Speed, r.p.m.	Power, b.hp.	Temperature of Air Entering Carbureter, deg. fahr.	Ratio, Air to Fuel, by Weight	Decrease in b.hp. from about 70 to 240 deg. fahr., per cent
300	6.80	75	15 to 1	11.00
	6.05	240		
400	9.55	75	15 to 1	15.72
	8.05	240		
500	11.76	72	15 to 1	14.95
	10.00	240		
600	13.80	70	15 to 1	14.82
	11.75	240		
700	15.45	70	15 to 1	14.25
	13.25	240		
800	15.50	85	15 to 1	5.48
	14.65	240		
900	19.30	120	12.5 to 1	9.34
	17.50	240		
1,000	21.80	70	11 to 1	14.70
	18.60	240		

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between 10 and 15 per cent.

This reduction in power can be satisfactorily explained by the increase in compression work and the decrease in the maximum pressure due to the increased temperature. The decrease is not wholly an unmixed evil, however. The engine can, at an increased air temperature, be made to operate between wider limits of fuel to air ratio or, to show greater flexibility and a smoother performance.

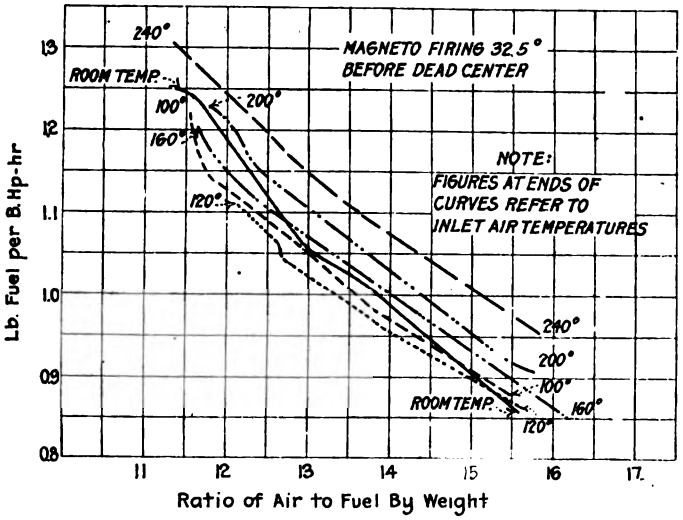

FIG. 12
Speed 300 r.p.m.

Moreover, the fuel economy, especially at the higher speeds, is not affected very much by variations in the air temperature. As a matter of fact it has been found, as stated by H. L. Horning at the 1919 Semi-Annual Meeting of the Society, that air heating will in actual road work give improved fuel economy even though the reverse may have been true on the engine test stand. This is due, no doubt, to the more positive carburetion and therefore better distribution with heated air.

GENERAL PERFORMANCE CURVES

In Fig. 15 is given a set of general performance curves of the engine as derived from these tests. They refer to air temperatures of 72 and 240 deg. fahr. respectively

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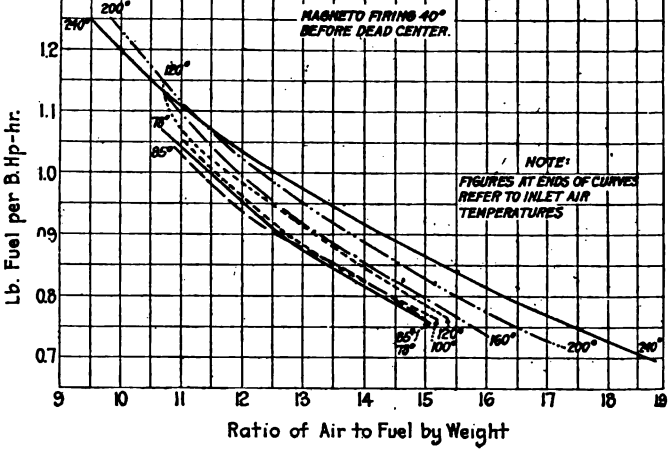
MAGNETO FIRING 40° BEFORE DEAD CENTER.
NOTE:
FIGURES AT ENDS OF CURVES REFER TO INLET AIR TEMPERATURES
Lb. Fuel per B.Hp-hr.
Ratio of Air to Fuel by Weight

FIG. 13
Speed 400 r.p.m.

and to a mixture ratio of 12 to 1. This ratio seems to give the most consistent power development throughout the range.

The engine was an old-type engine designed for use in an "8-16" tractor. It will be noticed that the brake horsepower of the engine at a rated speed of 1000 r.p.m.

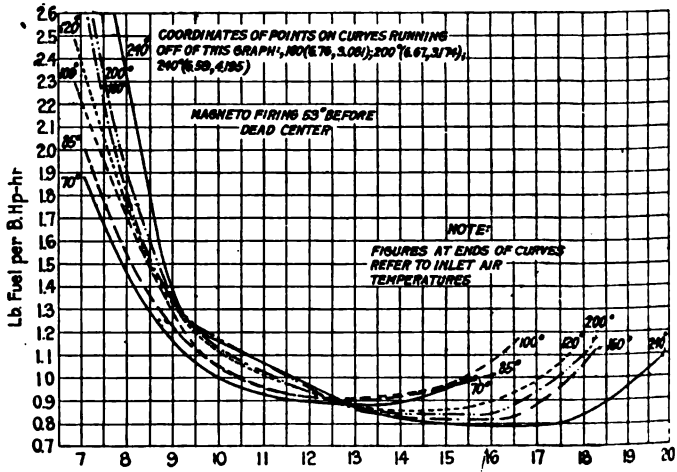
COORDINATES OF POINTS ON CURVES RUNNING OFF OF THIS GRAPH:-,180°(6.76, 3.081);200°(6.67, 3.174);
240°(6.59, 4.195)
MAGNETO FIRING 53° BEFORE DEAD CENTER
NOTE:
FIGURES AT ENDS OF CURVES REFER TO INLET AIR TEMPERATURES
Lb. Fuel per B.Hp-hr
Ratio of Air to Fuel by Weight

FIG. 14
Speed 1000 r.p.m.

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exceeded the rated pulley horsepower by more than 5 hp. at the lowest temperature and by 2.5 hp. at the highest.

The fuel economy at a ratio of 12 to 1 varies but little

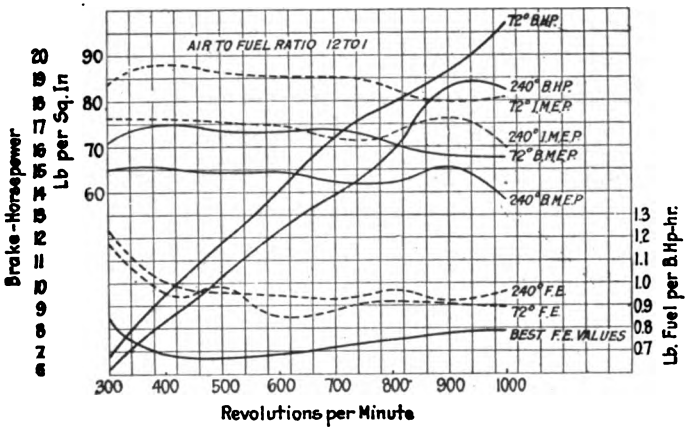

FIG. 15

with the speed from 400 to 1000 r.p.m. It is to be noted, however, that a fuel economy fully 20 to 25 per cent better than that at 12 to 1 can be obtained by using weaker mixtures as shown in the full-line curve.

In view of the importance of knowing just where the best performance occurs, there are given in Table 3 the air temperature and mixture ratio leading to the greatest

TABLE 3

Speed, r.p.m.	Fuel Consumption, lb. per b.hp.-hr.	Temperature of Air for Greatest Economy, deg. fahr.	Ratio by Weight, Air to Fuel, for Greatest Economy
300	0.85	160	16.25 to 1
400	0.68	240	19.00 to 1
500	0.67	240	17.80 to 1
600	0.68	160	18.25 to 1
		120	16.60 to 1
700	0.72	100	15.30 to 1
	0.74	70	16.00 to 1
		160	
		200	17.75 to 1
		240	
800	0.75	240	18.30 to 1
			18.00 to 1
900	0.78	240	15.70 to 1
1,000	0.80	240	16.00 to 1

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economy at each speed. It is of interest to note that here the highest air temperatures are very much in evidence. In other words, while rich mixtures and low temperatures

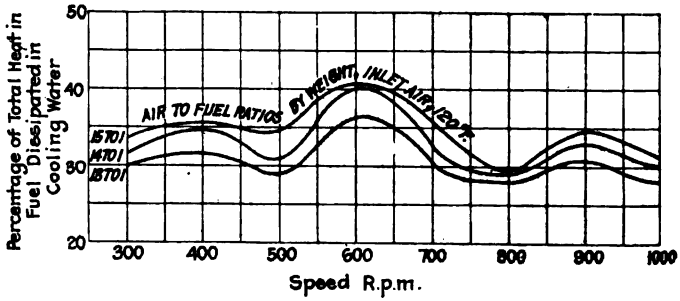

FIG. 16

tend to give maximum power, leaner mixtures and higher temperatures are conducive to the greatest fuel economy. It is a question whether this fact, in connection with the smoother operation at higher temperatures, should not be the guiding factor in engine design rather than simply a desire for maximum power. Another point of interest is that the greatest economy occurs at speeds of from 400 to 600 r.p.m., rather than at higher speeds.

In Fig. 16 is shown a set of curves indicating that the percentage of cooling loss is very little less at 400 to 600 r.p.m. than at the higher speeds. On the other hand, the curve in Fig. 17 shows that the exhaust temperature

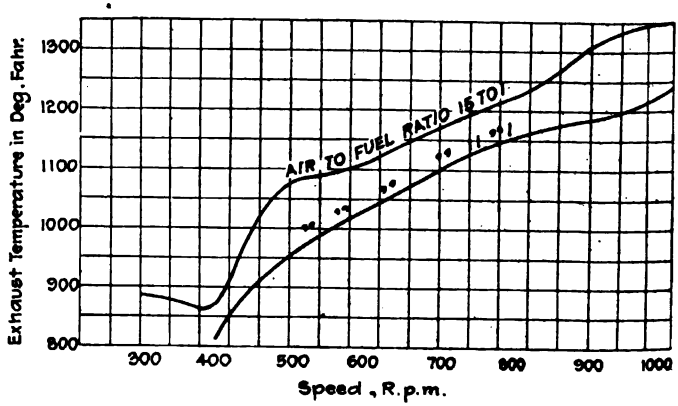

FIG. 17

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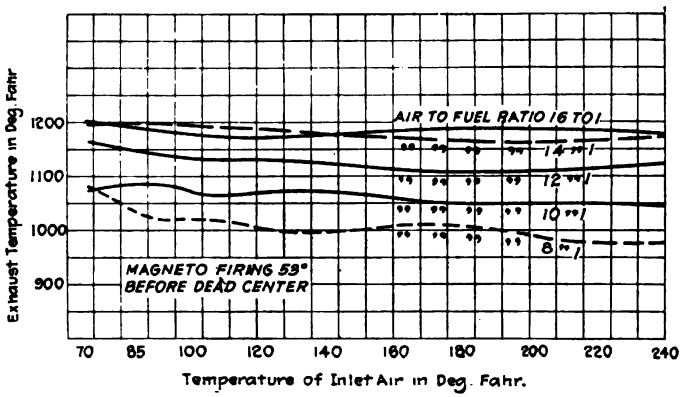

FIG. 18

increases with the speed. The indications are that the combustion, even with comparatively rich mixtures, is too slow to be fully utilized for power purposes at the higher speeds.

It is interesting to note that any increase in the air temperature does not influence either cooling loss or exhaust temperature at all. (See Figs. 18 and 19.) This leads to the conclusion that the mixture just prior to combustion, although at a slightly different temperature, is almost in the same state of evaporation in all cases. Since, as shown later, we have positive evidence that an

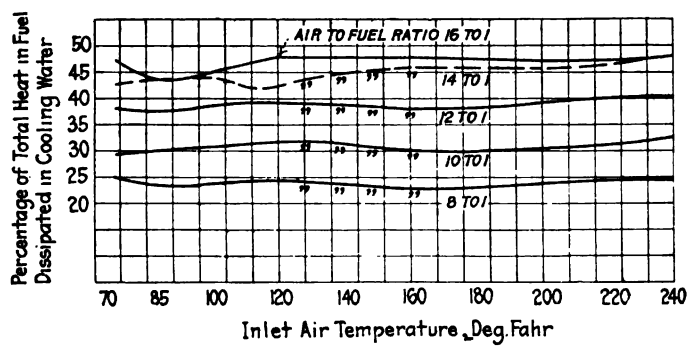

FIG. 19

air temperature of 240 deg. fahr. gives practically complete evaporation of the fuel before it reaches the cylinders, we can assume that even at low air temperatures

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the fuel is perfectly evaporated before combustion commences; it is evaporated during the intake and the compression strokes.

Interpretation of Results

It is interesting to inquire how far the results obtained could have been quantitatively predicted on the basis of known physical laws; or to what extent can an engine of unusual size or new type be designed and its performance predicted on the basis of advance calculations.

In some fields of prime movers, especially that of steam turbines, it is customary to predict the performance by an intelligent analysis of the physical occurrences known to take place from step to step and, by making proper allowances, estimate the future performance to within very close limits. It has been found possible to do very much the same thing in connection with continuous-combustion gas turbines. In this way a great deal of unnecessary, and often hopeless, experimentation has been avoided. Can we then follow a similar course in the case of an automotive type internal-combustion engine? There are many reasons, especially the uncertain character of the combustion process with over-rich mixtures and the complex character of some of the losses, why a very high degree of exactness cannot be expected. Nevertheless, it may be useful to see just which factors appear to remain unsolved after a reasonable attempt has been made to find the answer.

Assume an air temperature of 85 deg. fahr. and a ratio of air to fuel of 15 to 1 or practically the theoretical ratio for complete combustion without excess air. The fuel will have a lower heating value of 18,000 B.t.u. per lb. The air passing through the carbureter and the inlet manifold to the cylinder is subject to a cooling effect due to the evaporation of the fuel and to a heating effect caused by radiation from the exhaust manifold and the cylinder walls. The cooling effect can be calculated in advance on the basis of the specific heat of the liquid, usually about 0.4 to 0.5, and the heat of evaporation of the same.

The total heat absorbed from a fuel temperature of say 70 deg. fahr. to complete evaporation may be put roughly at 230 B.t.u. per lb. of fuel, or in our case $230/15 = 15.3$ B.t.u. per lb. of air. With a specific heat of 0.24 for air, the cooling effect would be

$$\frac{15.3}{0.24} = 64 \text{ deg. fahr.}$$

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As shown in Fig. 20 this is the actual cooling effect observed at a speed of 400 r.p.m. for a mixture of 15 lb. of air per lb. of fuel at an air temperature of 240 deg. fahr. At higher speeds the heating effect from the exhaust manifold is greater and the cooling through evaporation may be somewhat less. However, the curves in Fig. 20 show also that with an air temperature of 85 deg. fahr. there is no appreciable cooling of the mixture in passing through the carbureter. This means that the evaporation at this temperature is very incomplete, as

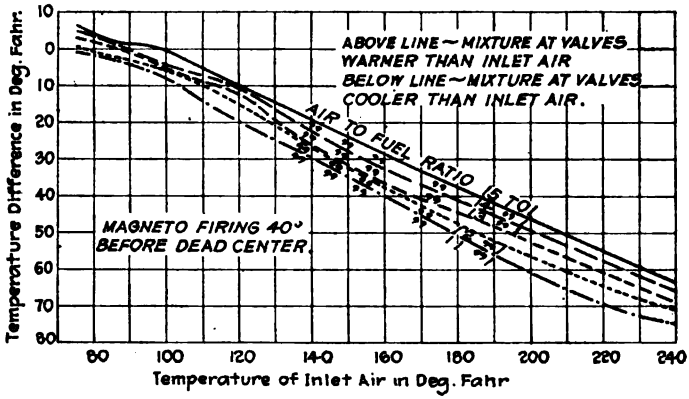

FIG. 20

can, for that matter, be clearly perceived by looking at the mixture through the peep-holes close to the carbureter; also that the effect of heating the manifold may be very appreciable.

Avoiding all speculation as to any heating in the inlet manifold and in the inlet valve, assume that the mixture enters the cylinder at 85 deg. fahr. It here comes in contact with the burnt gases remaining in the clearance space at the end of the exhaust stroke. The temperature of these gases, as will be seen later, may be assumed to be around 1600 deg. fahr. The volume of the clearance space is 42.3 per cent of the piston displacement. The weight of the burnt gas may be assumed to be

$$\frac{(460+85)}{(460+1600)} \times 0.423 = 11.2$$

or roughly 11 per cent of the weight of the entering air.

The average temperature of the mixture of the fresh charge and the burnt gases, disregarding the evaporation

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of the fuel to begin with, would be, since for 1 lb. of air there are 16/15 lb. of charge,

$$\frac{16/15 \times 85 + 0.11 \times 1600}{16/15 + 0.11} = 227 \text{ deg. fahr.}$$

This temperature will be lowered by the evaporation of the fuel in the hot cylinder but will be increased by the radiation from the cylinder walls, which may have a temperature at least in the clearance space of 700 deg. fahr., or more.[4] What the resultant effect will be can be estimated only on the basis of observations. From indicator diagrams taken at 400 r.p.m. it appears that the heating by radiation from the walls preponderates.

As a starting point for further calculations, the temperature at the beginning of compression has been taken as 275 deg. fahr. With the customary compression exponent of 1.3 and a volumetric compression ratio of 3.36, the end temperature of compression will be

$$1.44\ (460 + 275) = 1060 \text{ deg. fahr. absolute or } 600 \text{ deg. fahr.}^5$$

With a lower heating value of 18,000 B.t.u. per lb. of fuel, there are available per pound of mixture

$$\frac{18000}{16} = 1125 \text{ B.t.u.}$$

The combustion is, however, by no means instantaneous. Assume 70 per cent of the heat to be developed practically at constant volume in the clearance space, 30 per cent to go to after-burning and to cover cooling losses. The heat then remaining in the clearance space is

$$0.7 \times 1125 = 787 \text{ B.t.u. per lb. of mixture.}$$

In a paper[6] by the senior author presented at the 1919 Semi-Annual Meeting of the Society, is given a set of curves showing the variation with the temperature of the specific heat of the products of combustion. From the curve for specific heat at constant volume the average value to be used here is estimated at 0.236. The temperature increase in the clearance space will thus be

[4] See Dugald Clerk, The Gas, Petrol and Oil Engine, and C. A. Norman, *Transactions* of the American Society of Mechanical Engineers for 1918, page 745.

[5] With a volume ratio of V_2/V_1, the absolute temperature ratio is $\left(\frac{V1}{V_2}\right)^{n-1}$ where n is the compression exponent. In our case $\left(\frac{V1}{V_2}\right)^{n-1} = 1.44$ (See Marks, Mechanical Engineers' Handbook, page 318)

[6] S. A. E. TRANSACTIONS, vol. 14, part 2, p. 291.

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$$\frac{0.787}{0.236} = 3340 \text{ deg. fahr.}$$

The temperature reached will be

$$600 + 3340 = 3940 \text{ deg. fahr.}$$

The nature of the expansion from the maximum pressure is, of course, uncertain. It will be found, however, that the cooling loss to be expected is of the order of magnitude of the heat assumed to be developed by afterburning. In other words, the gases would expand adiabatically.

Under such conditions the expansion exponent may be taken from the author's paper previously mentioned from the curves for C_p/C_v and will for the temperature range expected be about 1.255. The temperature ratio is then 1.36.

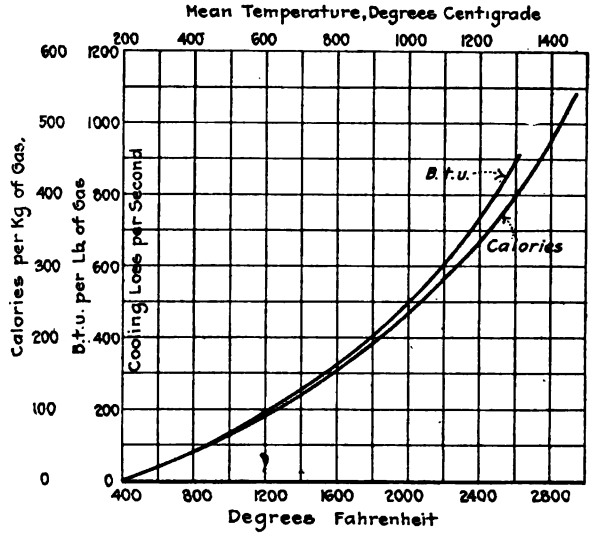

FIG. 21

Speed, r.p.m.	Fuel Consumption, lb. per b.hp.-hr.
300	0.86 (throttling)
400	0.76
500	0.71
600	0.76
700	0.76
800	0.80
900	0.86 (exterpolated)
1,000	0.96

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The end temperature of expansion is

$$\frac{3940+460}{1.36}-460=3240-460=2780 \text{ deg. fahr.}$$

We might now check the assumed cooling loss by a formula published by the senior author in a paper[1] previously referred to.

The formula is

$$L=3.2\frac{CR}{N}\sqrt{V} \text{ where}$$

L = cooling loss during the expansion stroke in B.t.u. per lb. of gas

R = the ratio of cooling surface to enclosed volume, sq. in. to cu. in., in our case 1.29

V = the piston speed in feet per minute; in our case, at 400 r.p.m., $V=\frac{2\times 400\times 5}{12}=335$ ft. per min.

C = a constant obtained by the author from certain experiments by Dugald Clerk and is read from curves in Fig. 21, which is reproduced from the original paper. The temperature referred to is the mean temperature during the expansion stroke

It is in our case

$$\frac{3940+2780}{2}=3360 \text{ deg. fahr,.}$$

With exterpolation for this temperature, C may be taken to be 1600 B.t.u. per lb. of gas.

The cooling loss is consequently

$$L=\frac{3.2\times 1600\times 1.29\sqrt{335}}{400}$$

$$=302 \text{ B.t.u. or } \frac{302}{1125}=26.8 \text{ per cent of the fuel heat.}$$

This value is at least of the same order of magnitude as the 30 per cent reserved for after-burning in our assumptions.

The net indicated work obtained from the process is the difference between the expansion work and the compression work per pound of gas.

The formula for both is

$$\text{Work per pound in B.t.u.} = \frac{RT_1\left(1-\frac{T_2}{T_1}\right)}{778\times(n-1)}, \text{ where}$$

[1] See *Transactions* of the American Society of Mechanical Engineers for 1918, page 745.

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R is a gas constant equaling 53.3 for air and 53.6 for average combustion gas
T_1 is the absolute initial and
T_2 is the absolute final temperature
n is the exponent of change, equaling 1.3 for compression and 1.255 for expansion in this case

The compression work per pound of air, neglecting the very small compression work on the fuel vapor, is

$$\frac{53.3 \times 735}{778 \times 0.3}(1 - 1.44) = 74 \text{ B.t.u. or}$$

$$74 \times 15/16 = 70 \text{ B.t.u. per lb. of mixture}$$

The expansion work per pound of mixture is

$$\frac{53.6 \times 4400}{778 \times 0.255}\left(1 - \frac{1.00}{1.36}\right) = 315 \text{ B.t.u.}$$

The net indicated work per pound of mixture is

$$315 - 70 = 245 \text{ B.t.u.}$$

The indicated work per pound of fuel is

$$245 \times 16 = 3920 \text{ B.t.u.}$$

The brake net work, with a mechanical efficiency actually determined for this engine at about 0.85, is equal to $3920 \times 0.85 = 3330$ B.t.u. One horsepower hour is equal to 2547 B.t.u. Consequently the amount of fuel necessary per brake horsepower-hour is

$$\frac{2547}{3330} = 0.765 \text{ lb.}$$

The actually measured values for the conditions of richness and temperature here assumed are given in the accompanying table.

It will be noticed that from 400 to 700 r.p.m. the check is surprisingly good. At higher speeds the fuel rate is higher than figured here. This may be caused by throttling through the carbureter and the valves; by greater heating of the charge through radiation from the exhaust manifold and from the cylinder walls; by insufficient velocity of combustion, and by other factors, all of which the authors hope to be able further to analyze later on, with the aid of the indicator and entropy diagrams.

Work of this kind was started in connection with this paper and gave some very interesting indications. Unfortunately, the operation of the indicator used was not satisfactory enough to warrant publication of the results.

THE DISCUSSION

O. C. BERRY:—What jacket-water temperature was maintained in these tests and what kind of fuel was used?

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The less volatile fuels require a much higher jacket-water temperature and more heat in the mixture to get good carburetion, than do the high-grade gasolines.

In comparing these results with the Purdue tests, it will be noticed that the curves are drawn to different coordinates, the lean mixtures being represented at the right-hand end of these curves and at the left-hand end of those in the Purdue paper. In these curves the chemically perfect mixture is obtained with 14.77 lb. of air per lb. of gasoline.

We are threatened with a shortage of fuel, and as Mr. Kettering expresses it, this is the one cloud on the automotive horizon. If we are to meet this situation in such a way that the automotive industry will continue to grow in the future as it has in the past, we must solve several problems.

In the first place, we must produce an engine that will use the fuel more efficiently, as has been very clearly pointed out in this paper. In this connection I mention the desirability of having the carbureter designed so that a complete adjustment can be obtained by a device on the steering post of the car. The device should be more than a mere "choke," it should make the mixture leaner or richer by the same percentage through the entire range from no load to full load. The value of such a device can be pointed out in this way. If a carbureter is adjusted so that it will give a rich enough mixture to start the engine and cause it to run nicely when it is cold, the mixture will be too rich when the engine warms up. Although without accurate data on this point, I would estimate that this excess fuel will often amount to 30 per cent. In other words, without a device of this kind one may be forced to waste one-third of all of the fuel used.

I have used a device of this kind for a number of years and would not willingly be without it. I start out with a good rich mixture and after I get well started I make the mixture continuously leaner until the engine commences to lose power. I then make the mixture alternately a little richer and a little leaner until I find a mixture that will give almost but not quite the full power. This is the mixture for best general performance in that it will give almost the maximum power and at the same time almost maximum efficiency. In case the engine heats up later or the day gets warmer, I can readjust the carbureter while driving. The operation is

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not difficult, is in fact enjoyable and it results in a marked increase in the miles per gallon of gasoline.

To be successful, a device of this kind must be so designed that the richest mixture obtainable is just barely rich enough to allow a cold engine to run nicely, and a separate device must be supplied for flooding the carbureter to start the engine. This is necessary to make it fool-proof. A large percentage of automobile drivers will flood the carbureter if such a thing is possible. If designed as suggested, the unthinking driver will get along as well as he could with any other fool-proof carbureter, and the skilled driver will be able to obtain ideal results.

Important as increased economy is, the fuel problem cannot be completely solved in that way. We must extend the fuel supply. The most obvious way to do this is to include in the engine fuel a larger part of the crude petroleum, or more "heavy ends." This would however result in two things:

(1) The poor carburetion resulting from the heavy ends would lead to excessive engine trouble and maintenance costs
(2) The heavy ends in the fuel would result in a violent kerosene knock

Mr. Kettering and the other men working with him have pointed out that the kerosene knock, or detonation, can be eliminated by producing a proper fuel blend. Alcohol, benzol and some other fuels, when added to the petroleum products, will do away with the knock entirely.

The staff of the Purdue Engineering Experiment Station and many other investigators are striving to develop a carbureting system capable of handling the less volatile petroleum products. We will soon know just how far it is possible to go in that direction, and what the limiting factors are. We feel confident that the limit has not been reached as yet, and even hope to see the time when we can carburet all of the more fluid petroleum products. In conjunction with the cracking processes of making gasoline, this may make it possible to convert petroleum into engine fuel, lubricating oil and petroleum coke. The alcohol and benzol added to this petroleum fuel to produce a proper blend will again add to the volume of the available fuel, so that there is still reason to hope that the fuel problem can be solved, at least for the immediate future.

C. A. NORMAN:—The distillations are given in the paper. In getting better efficiency, it is desirable to

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have the steering-post carbureter adjustment. If a carbureter gives a rich enough mixture to start nicely when the engine is cold, when it warms up the mixture is too rich. We have no accurate data on that point. It will amount to 30 per cent in cool weather; in cold weather, to more than that. This means the throwing away of part of the gasoline. With a steering-post adjustment the engine can start with a rich mixture and warm up; if the mixture is richer than necessary, it can be made leaner. It can then be adjusted to a point just below the highest power, the point best suited for the best performance.

In a large way, there are two problems involved in solving this fuel question. One is to develop a carbureter that can utilize the heavier oil products. But these heavier petroleum products produce a heavy knock. As has been pointed out by Mr. Kettering and others, the solution of this problem seems to be through the fuel blend, using petroleum, alcohol, benzol or some other fuel of that character, introduced to do away with the detonation.

J. H. SHOEMAKER:—Have any engineers tried two-spark or multiple ignition? As an instance, during the war a seaplane was unable to rise from the water; a two-spark ignition was installed, which gave an increased number of revolutions per minute and the additional power needed for rising. I do not know whether that gave greater fuel economy.

W. G. WALL:—Professor Berry's remarks suggest how much fuel is lost, after engines become heated, by not shutting off the excess gas. Would it not be feasible and possible to attach a thermostat in the water line and connect it to the needle-valve of the carbureter so that, as the engine heats up, the amount of gasoline will be cut down? The temperature of the water in the water-jacket bears only a comparative relation to the temperature of the engine, although such a relative change from a cold to a hot engine, which would operate the thermostat, could readily be used to cut off a part of the gasoline supply. Has this method been used?

F. D. HOWE:—I recently received a carbureter that has a thermostat in the gasoline bowl. The viscosity of the fuel changes with its temperature, so the fuel temperature is what we need to measure. It looks promising to me.

CHARLES GUERNSEY:—Professor Berry recommended

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the use of steering-post control to regulate the quality of mixture in accordance with the needs of the engine. We have tried this construction and have been forced to abandon it. We at one time used a carbureter which was fitted with an adjustment operated from the steering column. It did not work out satisfactorily in truck use. The driver would set the adjustment to the rich-mixture position for starting and forget to reset the adjustment until the engine began to labor heavily.

Both Professor Berry's and Professor Norman's studies have shown that it is possible to operate an engine smoothly within very wide limits of mixture proportion. The result was that these trucks were operated a great portion of the time away over on the rich end of the mixture range, resulting in high gasoline consumption, heating and serious carbon deposits. I am inclined to agree with Mr. Wall's suggestion that a thermostat be used in such a way as to enrich the mixture when the engine is cold, coming down to the standard adjustment after the engine has reached the normal temperature.

MR. SHOEMAKER:—Would it not be practicable with such a device to have it held in the lean-mixture position by a spring, so that the driver would be forced to hold it long enough to get the engine up to its power?

PRESIDENT J. G. VINCENT:—That has been found desirable in many cases; otherwise, the engine would run on too rich a mixture, and accumulate compounds in the crankcase that are not wanted there. The question was asked whether two sparks might not aid in economy. Would the engine run with a leaner mixture if two sparks were used?

ROGER CHAUVEAU:—That depends largely upon the shape of the cylinder. We found, in aviation, where we used overhead valves, that two sparks had very little effect. On the other hand, in a T-head cylinder if the spark-plugs are placed in the very best location, from 20 to 25 per cent better fuel economy can be obtained. In an L-head cylinder this runs from about 6 to 12 per cent. There are other features in the two-spark ignition which are of advantage. It is possible with two-spark ignition to run the engine with less spark advance, which tends to prevent overheating and partially overcomes the pinking and kerosene knock.

PRESIDENT VINCENT:—What is the effect on the power?

MR. CHAUVEAU:—Two-spark ignition will increase the

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power, according to the shape of the cylinder-head, from 10 to 20 per cent.

T. KARGAU:—What is the effect on slow-speed engines?

MR. CHAUVEAU:—The speed of the engine counts, of course. If it is a question of an engine speed of 600 to 800 r.p.m., the effect will probably be approximately one-half of the figures mentioned above, as these figures were based on engines running from 1500 to 2000 r.p.m.

E. T. BIRDSALL:—In regard to the control of the carbureter from the steering-post, some time ago, in my enthusiasm to get the correct mixture I installed a Master carbureter on my car. After that experience I am through with attempting to give the driver control of the mixture. I became so tired of juggling that lever that I took it off and, although I got better results, life is too short for such a thing. If that is too much trouble for me, with all my enthusiasm, it will not appeal to a truck driver. My contention for years has been that the only way to put a carbureter on is to set it as nearly right as possible, and then dip the whole thing in solder so that the driver cannot change it.

In regard to economy, I have been making some experiments in crankcase dilution, which is, of course, closely allied to economy. With the choking method we have been putting all kinds of fuel into the crankcase. On my own engine I have aluminum pistons. I can tell very closely the stage of my crankcase dilution by the piston slap. I want to avoid that, but I want to be able to start promptly in cold weather and so I have been trying out various primers. Last November I put on a type of primer that boils the gasoline. The level in the primer chamber is the same as that in the carbureter. I have abandoned the use of the butterfly choker. I have found that with this device I practically eliminated crankcase dilution at least for three months. It is running now, and the pistons have not notified me as yet of any excess of gasoline in the crankcase. I also get less back-firing when the engine is cold.

This device, if operated when the engine is not running, produces a vapor or fog which does not condense. It simply floats off into the air, and can be lighted with a match. I believe there are two or three of these devices on the market and they should eliminate probably 75 per cent of the crankcase dilution and also give better economy by not wasting gasoline in the crankcase.

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Going back to the steering-post adjustment for the ordinary truck drivers, which applies also to 90 per cent of the ordinary passenger-car drivers, I am absolutely against it. They will not operate them properly, if they operate them at all. The more adjustments the driver has at his command, the poorer is the economy obtained from the truck.

PROFESSOR NORMAN:—The questions have been very largely answered by other speakers in the course of the discussion. I shall therefore mention only a few points.

The temperature of the cooling water was kept as nearly constant as possible in the tests; at about 200 deg. fahr. at the point of leaving, the rise being about 70 deg. fahr.

Regarding the influence of two spark-plugs, some illuminating tests have recently been carried out by the Bureau of Standards. The velocity of flame propagation was measured in a 5 by 7-in. Liberty engine while the engine was actually running. From some computations I have made it appears that, even at 1800 r.p.m., the velocity of flame propagation with a single spark-plug was enough to spread the combustion through the charge before the end of the working stroke. It was not enough, however, to ignite the charge completely and burn it in the clearance space at a reasonably constant volume, say in one-eighth of the stroke. Since greater efficiency is obtainable by combustion in the clearance space than by combustion during the whole stroke, the efficiency of a 5 by 7-in. engine at 1800 r.p.m. can be improved by two spark-plugs. That of a smaller engine, or a 5 by 7-in. engine at a lower speed, cannot be improved in the same ratio.

The type of fuel used is specified in great detail in the paper. It was a standard gasoline and the constancy of quality was checked repeatedly by distillation tests. The test here reported is only the first half of a test. It is proposed to run the same engine on kerosene and compare its performance when burning that kind of fuel with that obtained from gasoline.

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RELATION OF TIRES TO TRUCK EFFICIENCY

By S V Norton[1]

The discussion is largely in regard to the ability of a truck to deliver merchandise economically under a given set of external conditions. The matter of truck tire equipment is reviewed in the light of recent experiences of many operators and service men. The general functions of tires, securing traction, cushioning the mechanism and the load and protecting the road, are elaborated and six primary and seven secondary reasons given for the use of pneumatic tires on trucks within the debatable field of 1½ to 3½-ton capacity. The deciding factors in tire choice, those affecting time and those affecting cost, are stated and commented upon, the discussion next being focused on how tires affect these factors. Considerations relating to both truck and tire repairs are then reviewed. Separating the field for each type of tire into three parts, the imperative, the economic and the optional, within one of which the operator can reasonably locate his requirements and decide upon his equipment, the specific considerations involved in making this decision are then enumerated.

In an excellent paper, entitled Pneumatic Tires for Trucks,[2] by B. B. Bachman, read before the Society February, 1919, the principal advantages and disadvantages of pneumatic-tire equipment were set forth clearly and forcefully. In my judgment, his paper is the most convincing presentation of this subject that has yet been made. Notwithstanding the apparent limitations of the economical use of pneumatic tires due to external factors, so much has been claimed in their favor since his paper was written that it seems advisable to analyze the relation of both solid and pneumatic tires in respect to their effect upon motor trucks in practical operation.

A distinction is here made between the inherent "ability" of a truck to overcome road friction and the force of gravity due to its engineering design and its ability to deliver merchandise economically under a

[1] B. F. Goodrich Rubber Co., Akron, Ohio.
[2] S. A. E. Transactions, vol. 14, part 1, p. 459.

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given set of external conditions. It is largely in the latter sense that I shall discuss the subject, although I realize that the members are perhaps more especially interested in the former. In the last analysis, however, trucks must be designed and built to meet the needs of their buyers, who use them to move freight under widely differing and complex circumstances.

Viewing the problem from this angle, I have sought information not only from truck manufacturers and their engineers, but from truck salesmen and operators in all parts of the country, as well as from tire dealers and those upon whose local service in the field the continued and successful operation of the truck depends. The information presented is not theoretical, nor based upon the experiences of selected operators whose delivery problems would invariably point to the same conclusion, but is rather a composite of the opinions of hundreds of truck operators engaged in handling all kinds of merchandise, and of hundreds of men whose business it is to help keep those trucks running economically. Because of the concentrated study that is being given to all phases of motor transportation, some factors in the problem are almost as variable as a kaleidoscope. Hence, conclusions which may appear sound today may have to be modified by changes that are gradually but constantly taking place. For instance, truck design is being altered and improved. Tires are being built better and stronger. Roads are being improved, while experience is pointing the way to the more intelligent use of motor trucks through systems and devices heretofore unknown. It therefore seems worth while to view the question of truck tire equipment in the light of recent experiences of many operators and service men, to get a clear idea of the advantages and limitations of each type.

General Functions of Tires

The functions of tire equipment are: To secure traction, cushion the mechanism and the load and protect the road. From the truck operator's viewpoint the first two are of more importance than the third, although it is becoming increasingly necessary to safeguard the taxpayers' investment of millions of dollars in improved highways through proper restrictions upon the vehicles that use them. To perform these functions, solid, cushion and pneumatic types of tire are available. The general knowledge of the construction and

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peculiarities of each type makes it unnecessary to describe them, except to say that the cushion tire is in reality a solid tire, usually made from a specially resilient rubber compound, so designed in contour or internal construction as to be soft and yielding under pressure. Its construction generally renders it less rugged and hence more susceptible to early failure under severe service conditions. Since there are relatively few cushion tires in service at present, we may profitably confine our discussion to the solid and pneumatic types.

At present, the accepted field for pneumatic tires is on trucks up to 1½ tons capacity, and for solid tires it is on trucks of 3½ tons or over. Between these two capacities the field is debatable, and the choice cannot be made intelligently without a careful analysis of the important factors involved in each individual case. If the operators of trucks in this debatable field could surely avail themselves of all the advantages claimed for pneumatic-tire equipment, no trucks would be found on solid tires, since the claims embrace nearly everything the truck owner desires. Let us review the claims made on behalf of the tires themselves and then study them in relation to various external factors which should have an equal if not greater bearing upon the choice of equipment.

From several hundred truck-tire salesmen, as well as truck operators throughout the United States, whose opinions were asked as to the principal advantage to be gained from the use of pneumatic tires in the debatable field above described, the following table shows the reasons given with the percentage of replies for each:

	Per cent
Greater traction	40
More cushioning	28
Higher speed	21
Lower repair bills	5
Saving in gasoline	4
More work possible	2
	100

Other reasons were given for the use of pneumatic tires, but they were thought to be of secondary importance. They were

(1) Less breakage of loads
(2) Reduced fatigue of drivers

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(3) Less depreciation of trucks
(4) Reduced depreciation of roads
(5) Adaptability of trucks to farm use
(6) Lighter weight trucks possible
(7) Increased earning power

Deciding Factors in Tire Choice

It is evident that a careful study should be made of all the factors involved before deciding which type of tire to use. For the purposes of this discussion the factors may be divided into three groups; engineering features, practical operating features and features of tire service in the field. In taking up the engineering aspects I speak briefly and frankly as a layman and not as a truck engineer. Before changing tire equipment from solid to pneumatic it should be realized that to gain certain possible advantages other definite disadvantages must be faced. First, the wheels of the vehicle must be cut down to receive pneumatic tires. The cost of this will vary according to local conditions, but it is a large item of expense. As the pneumatic tire has a larger actual than nominal diameter, and since in many cases a pneumatic of larger nominal diameter must be used than is required for a solid tire, to secure the necessary carrying capacity, proper allowance should be provided for both body and fender clearance. It should also be remembered that the larger sectional diameter of the pneumatic tires will affect the steering clearance and that the truck will be unable to turn in so short a radius as it did on solid tires. This is especially important in negotiating turns in narrow streets and alleys, as well as in garages with limited floor space. As the larger diameter of the pneumatic tires will affect the gear reduction, the change will have a corresponding effect on the mechanical ability of the truck. If the change is made, will the truck be able to "make the grade" so far as particular problems are concerned? Will it materially affect the pay-load capacity of the truck? Will it reduce ability to haul trailers? What will be the effect upon the engine?

The increased maximum speed due to the larger diameter of the pneumatic tire will be relatively slight, provided the engine is governed to run at the same speed as formerly. If the change is made to get more speed, either the gear ratio must be reduced and the ability of the truck thus still further reduced, or the governor

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must be opened and the engine speed increased. There is danger here, however, as speed induces extra vibration, joints begin to loosen and before long the engine may be literally racked to pieces.

As the engines in some trucks now have pressure-feed oiling systems, they can more safely withstand the extra speed, so far as lubrication is concerned, although this feature should be carefully investigated, as there is danger of damage from this cause with resultant expense. Still another factor which should be considered is the tax upon the cooling system if the engine is speeded up. Again, additional speed calls for greater braking ability. Before changing tire equipment assurance is necessary that with increased truck speed and the limitations imposed on the diameter of the brake-drums by the reduced diameter of the wheels themselves, the machine will still have sufficient braking ability. Brakes designed for slower speeds but used under more severe conditions, will inevitably require more frequent renewal and may not even safely perform their required function. In fact, an engineer of one of the larger tire companies, advocating the use of pneumatic tires on trucks, says

> On account of the comparatively high speed of the pneumatic-equipped trucks, it is necessary to equip them with brakes having 100 per cent more capacity than is the case with solid-tire trucks.

The question for decision is whether or not the truck can be so equipped and, if not, whether it can be safely operated on pneumatic tires.

Of no less moment than the features already mentioned, so far as the dependability of the truck is concerned, is the question of the air supply, since pneumatic tires may require from 90 to 160 lb. per sq. in. inflation pressure. As hand pumping is out of the question, a power-driven pump on the truck, or one close at hand, becomes a necessity. Relatively few trucks now running can properly accommodate a power pump. With a transmission arranged so as to permit of power take-off, a pump attachment can be put on. If the transmission is mounted amidships, it is possible to provide a device to take power from the drive-shaft. If, however, the truck has its transmission in a unit with its engine, with no provision for power take-off,

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there appears to be no satisfactory way of attaching an air-pump, since the magneto and water-pump shaft is generally too light for power take-off. There is, of course, the possibility of adapting an electrical system for this purpose, but this does not seem practicable, because of its cost and the fact that such apparatus is not standard practice.

While these mechanical considerations apply particularly to trucks now in operation on solid tires, most of the same problems are involved in changing the equipment on trucks manufactured but unsold. The buyer usually looks to the agent for advice regarding tires; he should therefore satisfy himself that the agent's counsel is based upon positive facts and endorsed by the manufacturer. Otherwise, more or less disappointment and dissatisfaction over the performance of the truck can be expected if the tire equipment is changed to pneumatic before delivery. To sum up, since so many important technical features are involved, it is well to seek the advice of the truck builder before changing equipment from solid to pneumatic tires. No one else knows so well the probable effects on various parts, nor can anyone advise more intelligently as to the probable loss or saving that such a move would entail upon the mechanism of the truck.

Let us next consider the practical operating features that must be taken into account in determining which type of tire equipment will make the truck most efficient in service. Broadly speaking, the efficiency of a truck in performing its function depends upon the amount of time or money, or both, that it saves for the shipper, as compared with any other means of haulage. While it is difficult to separate all the factors bearing upon these two items, they may be roughly classified as follows:

Factors Affecting Time	Factors Affecting Cost
(1) Distance of hauls	(1) Amount of pay-load and overload
(2) Traffic congestion	(2) Condition of roads; effect on tires and truck
(3) Speed of delivery	(3) Number of trips per day
(4) Regularity of delivery	(4) Cost of operation
(5) Condition of roads; effect on speed of truck	(5) Cost of upkeep
(6) Number of trips per day	(6) Cost of substitute equipment
(7) Time out for repairs, etc.	

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The question of how tire equipment bears upon these factors can only be answered after careful analysis of each particular case. However, certain principles can be applied to all cases. To begin with, from 75 to 225 per cent more must be paid for pneumatic than for solid tires. The latter figure includes the cost of spare tires, which are indispensable at the present stage of development. So far as is known, there are no dependable figures indicating the relative cost per mile of the two types, because pneumatic truck tires have not been used long enough to make reliable comparisons. From such information as is obtainable, however, it is my belief that it will cost from two to three times more per mile to run on pneumatic than on solid tires. To offset this increased cost there should be a corresponding or greater saving in one or more of the factors already enumerated, as affecting the operating efficiency of the truck.

How Tires Affect Time Factors

Let us now inquire how pneumatic tires may affect the time factors, assuming that the mechanical features of the truck are such as to permit of their use. If the truck is engaged in long-distance hauling with relatively few stops, pneumatic tires will almost invariably save running time, due to the fact that they absorb the road shocks so much more easily than do solid tires. By theoretical tests in our laboratory we have found that, for a given load, pneumatic yield over four times more than solid tires. Hence a truck can be driven over long distances at much higher speeds on pneumatic than on solid tires without fear that it will be racked to pieces. It should also be noted that the drivers' fatigue in such cases is far less on pneumatic than on solid tires. In fact, some operators have considered this so important that they have placed cushions with special springs in their drivers' seats.

Up to the present, however, very few trucks as compared with the total number in operation, certainly less than 5 per cent, are engaged in long-distance hauling. The great majority of trucks operate in cities where traffic congestion is such that they cannot possibly attain a speed of over 10 m. p. h., while their average speed is from 5 to 8 m. p. h. For such speeds there is no possible saving in the list of time factors to offset the extra cost of running on pneumatic tires. Moreover,

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the gain will be still further reduced by idle time at loading and unloading points. In many cities an effort is being made to reduce the maximum legal speed at which trucks may operate because of the many serious accidents attributed to them. Hence, increase of driving speed within city limits may be prevented by ordinances limiting the speed of trucks. Light delivery vehicles, running on pneumatic tires, are sometimes operated at higher speeds than are legal, but these do not properly come within the "debatable field" and are not considered as dangerous as the heavier vehicles.

In certain kinds of business such as the wholesale delivery of milk, gasoline, ice, etc., the regularity of service is the most important factor. Here the use of heavy-duty pneumatic tires is fraught with danger, due to the possibility of delays caused by punctures and poor tire service. Many operators in these and kindred lines have said that it is more important to deliver goods regularly and on time than to save a few dollars on truck upkeep. Failure in this means loss of the customer. One large truck-fleet operator in this group uses no pneumatic tires of over 6-in. section because solid tires on some good make of cushion wheel have always given him greater satisfaction at less cost than have larger pneumatic tires. Such equipment usually lasts for more than 2 years without trouble.

The condition of the road surface has a very important bearing upon the time element, for it has a direct effect upon the truck speed. In fact, under certain circumstances, the increased traction afforded by the heavy-duty pneumatic tire makes it possible to operate the truck, while if it is equipped with solid tires it cannot be driven at all. This is particularly noticeable in rural districts where there are no hard-surfaced roads.

In the farm lands and citrus groves of the South, where there is so much sandy bottom and so little surfaced roadway, it is practically impossible to operate a truck equipped with solid tires. However, a truck equipped with heavy-duty pneumatic tires can operate practically anywhere and is not dependent upon the highway for traction. Under such circumstances, the ability gained by the use of the pneumatic tire is worth 100 per cent more than that of the solid tire, no matter what its cost, for the latter is well-nigh useless. It must not be supposed, however, that there are no circumstances under which pneumatic tires will fail to perform their

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function unassisted by anti-skid equipment. The need for proper tire and chain clearance in changing from solid to pneumatic tires is again obvious, for, if due provision is not made, the time factor may occasionally be seriously and adversely affected.

One of the advantages most frequently mentioned is the greater number of trips per day which can be obtained from a truck equipped with pneumatic tires. So far as this factor alone is concerned, there is no doubt that the advantage is in favor of the pneumatic tire.

One more important factor affecting the time element is the number of hours the truck is laid up for repairs. Let us consider separately the time lost on account of tire trouble and that for all other reasons. In comparing the relative amount of time out for tire trouble for solid and pneumatic tires, the advantage lies wholly with the former. Barring occasional lay-ups caused by defective material or workmanship, solid tires can be depended upon to give uninterrupted service from the time they are applied to the time they have worn down to the renewal point. An appointment can then be made in advance with a tire service station without seriously disturbing regular truck service, and the worn tires replaced with new ones. There is hardly a sizeable city in the United States that does not have one or more hydraulic presses for this purpose and well-equipped service stations with ample stocks of solid tires. It is therefore only a question of laying up the truck a few hours at rare intervals, which can be planned so as to interfere very little, if at all, with the regular use of the truck. While the condition of the roads over which the truck operates influences to a certain extent the mileage delivered by solid tires, and hence the frequency of lay-ups for renewals, this factor is far less important for solid than for pneumatic tires.

Owing to the comparative vulnerability of pneumatic tires, they are far more likely to require time out for repairs and replacements. In the first place, they cannot withstand the same amount of overloading as solid tires, and when they are overloaded they are especially apt to give out. Such "failures" usually occur when the truck is in action and away from a service station. If the operator has a spare tire he may make the change on the road, although the evidence seems to indicate that it requires a skilled mechanic to do this and that it cannot be done easily or quickly. Most operators of trucks

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find it impossible to change a tire in less than 1 hr. under best conditions; under bad conditions it requires 2 or 3 hr. Punctures do not seem to be so frequent or so costly in point of time as blowouts due to cutting and chafing of side-walls from ruts, as well as to under-inflation and overloading. While solid tires are cut and torn by ruts, they are not so dangerously weakened by the process, and they rarely give out unexpectedly. If regularity and dependability of service are sought, these will be far more likely to be secured with solid rather than with pneumatic tires.

In comparing the time out for causes other than tire trouble, we find a variety of conflicting claims, although it seems to me the evidence favors the use of pneumatic tires. On the other hand, some claim that the use of pneumatic tires accelerates the wear of certain parts such as bearings, bushings and steering-knuckles and that a correspondingly greater amount of time is required for their adjustment and renewal. Moreover, many owners state that the use of pneumatic tires on trucks causes their drivers to overspeed and to take more dangerous chances that result in accidents and time out for otherwise unnecessary repairs, than is the case with solid tires.

How Tires Affect Cost Factors

In discussing the factors affecting the time element I have purposely avoided reference to the cost of the time, although I realize that these items all have a relative money value. In turning to the factors affecting the saving of money, it will therefore be necessary to refer to that aspect of some of the time features already mentioned. Moreover, although the two are so closely related that it may be difficult to distinguish between them, let us next consider the effect of solid and pneumatic tire equipment on the various money factors involved.

The amount of work a truck can perform, and hence the saving or profit it will show, depends largely upon the amount it can carry, or its pay-load. It is generally held that the more the truck carries, the more it earns or saves. The result of this belief is the well-nigh universal tendency to overload trucks beyond their rated capacity. In fact, many operators maintain that they cannot use trucks profitably unless they overload them. I shall not here attempt to debate the wisdom of this

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philosophy, but in analyzing the problem the fact must be faced that nearly all operators do overload their trucks and there seems to be no simple or effective way to prevent it. It is not uncommon to find trucks carrying twice their rated capacity.

When it comes to durability under this usage, there seems to be no doubt that solid tires will not only carry heavier overloads but will last longer in such service. All agree that the life of the heavy-duty pneumatic tire is short when overloaded. This seems the most important and least understood factor in the entire list. Apparent savings may be offset or overbalanced by the additional trips that become necessary when an overload cannot be carried. The use of pneumatic tires automatically places a lower limit upon the pay-load which can safely be hauled under *any* conditions.

Closely allied to the cost of overloading pneumatic tires is that of underinflation. In this case the constant and extreme flexing has a tendency to weaken the side-wall, making it much more likely to fail in service. It is held that drivers should give the same attention to tires as they give to water in radiators, oil in engines or gasoline in tanks. This is only another way of saying that the driver must be careful not to abuse his truck. Those who employ drivers realize how difficult it is to get men to watch these details, and the fewer such points requiring the driver's care and attention the more likely it is that the truck will run continuously and economically. While solid tires are not invulnerable, they are more nearly fool-proof and less expensive to maintain in working condition.

In addition to the likelihood of incurring expense from overloading and underinflation, there is the danger of ruining pneumatic tires from running them when loaded or overloaded after they have been punctured or blown out. It is not uncommon for drivers to ruin practically new tires by not stopping trucks as soon as tire trouble is suspected. A single blowout or puncture under such circumstances may cost from $25 to $100.

The condition of the roads over which the truck travels not only affects the speed or time factor, but has an important bearing upon the life of the tires and hence upon their cost. Pneumatic are subject to more damage than solid tires when run over roads with deep ruts because of chafing and cutting of the side-walls.

In attempting to collect data as to mileage on pneu-

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matic tires, many varying claims and little information based on records of a dependable nature were found. Operators are apt to exaggerate both high and low mileages, due to personal satisfaction or disgust, as the case may be. Most operators when questioned closely regarding averages will admit that they have not used pneumatic long enough to obtain reliable figures for comparison with solid truck tires. Hence, none but general conclusions are possible at this time. The mileages reported, from Maine to California, varied from 200 under adverse conditions such as bad roads, overloads, careless drivers, etc., to 25,000 miles on lighter trucks, over good roads and with proper care. Tires in city service usually give better mileage than those in use in the country. With rare exceptions the mileage delivered by solid is considerably greater than that from pneumatic tires in the same class of service.

Where the earning capacity of the truck is concerned, as judged by the number of trips per day, the advantage seems to lie with pneumatic-tire equipment, provided the runs are long enough and not restricted by such factors as traffic congestion and delays at terminals. In most cases the increased speed made possible by pneumatic tires can be converted into greater earning capacity, with little or no increase in overhead expenses.

As before suggested, there are certain conditions under which trucks on pneumatic can make trips when those on solid tires cannot be operated. Hence their earning capacity is just so much greater. But a new and interesting argument has recently been advanced on behalf of pneumatic tires, due to certain changes in the conduct of the business of farming. The ever-increasing use of gasoline engines for tractors, threshing machines, etc., requires the delivery of gasoline and oils direct to the farmers' door or barn. Oil men who own their own trucks and work on a purely commission basis frequently find it necessary to drive through the farmers' barnyard. It has been noted that trucks having pneumatic not only negotiate the unpaved roadways more easily, but do less damage than those having solid tires, and hence are looked upon with more favor by the farmers they serve.

When considering the relative effects of solid and pneumatic tires on the cost of operation and upkeep, a wide variety of opinions are expressed but very few conclusions based upon accurate cost records. In every other kind of business an intelligent analysis based on cost

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figures is considered necessary in arriving at conclusions. But few truck operators have yet realized the value of such records as applied to the cost of operation and maintenance of trucks. Hence the reliable data available are meager.

Let us briefly examine the items which should be included in such costs, and consider how they are affected by solid and by pneumatic tires. The following items are usually not affected by tire equipment:

(1) Interest on investment
(2) Insurance
(3) Taxes and license
(4) Garage
(5) Supervision
(6) Wages of driver
(7) Wages of helper

Those shown below may vary according to the type of tires used.

(8) Depreciation
(9) Gasoline
(10) Oil
(11) Tires
(12) Repairs due to (*a*) wear and (*b*) accident

Considering these in the order given, there are, so far as known, no dependable figures covering depreciation upon which to make comparisons as no trucks have been run long enough on pneumatic tires to determine their effect on the ultimate life of the truck. While there is a difference of opinion among engineers, most maintain that the increased engine speeds of trucks designed for use on solid but changed to pneumatic tires will tend to wear out all moving parts more quickly than if the tires had not been changed. As to the relative consumption of gasoline and oil, very few reliable figures are available, but the best informed operators are inclined to feel that there is little if any saving in these items, particularly on short hauls. On long hauls, however, the advantage seems to lie in favor of pneumatic tires.

When it comes to cost of tires there is no question. The cost of pneumatic averages from two to three times that of solid tires. This is due to the higher initial cost of the equipment and the spare tires, their greater susceptibility to abuse and accident and their lower average mileage. It is, of course, possible to have pneumatic

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tires repaired and retreaded, but this process has not yet been satisfactorily worked out for solid tires, at least to the point that is considered dependable or economical. The question of tire service, however, including all these features, will shortly be discussed.

Truck Repairs

So far as the cost of truck repairs is concerned, comparative data of a reliable nature cannot be obtained, for in most cases trucks equipped with pneumatic tires have not been used long enough to make satisfactory comparisons. The evidence indicates, however, that, excepting the engine, repairs will cost much less for trucks using pneumatic than for those using solid tires, due to reduced vibration. If the engine is not run at excessively high speeds or continually overworked, it will prove less subject to damage if pneumatic tires are used.

Dependable figures cannot yet be obtained on the relative cost of renting substitute vehicles to replace trucks using pneumatic and solid tires which have been laid up for repairs. A superintendent of a large truck fleet using both types states that he lays up solid-tired trucks four times a year for overhaul, while pneumatic-tired trucks are laid up only three times. In any event the variation in this item of expense will not be large, provided the trucks are carefully inspected and maintained.

Summing up the factors affecting the saving of time and money, the conclusion is reached that no general claims in favor of pneumatic-tire equipment on trucks coming generally within the debatable field can be substantiated, and that the work to be done by each specific installation must be analyzed carefully before either type of tire can be safely considered the more economical.

Having reviewed the engineering and practical operating features, let us now enumerate the operator's difficulties concerning tire service. As the nature and extent of service for the maintenance and renewal of solid tires are well known, it seems unnecessary to comment upon them except to say that years of study and competition have developed this end of the business to a remarkably high degree, so that many well-equipped service stations can be depended upon for instant attention, in many cases by day or at night, whenever it is needed.

The manufacture of heavy-duty pneumatic tires of 6-in. section and larger is, however, a relatively new development. Less than a third of the manufacturers of

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passenger-car tires have actively started to make heavy-duty pneumatic truck tires, for they realize that the job of building a tire which will stand up under present-day use and abuse is not easy. Moreover, the task is not finished when the tire is removed from the heater. It must be sold to the dealer who, in turn, must not only guarantee the tire, but must place himself in a position to give the truck operator service. This means that he must install a high-pressure air-pump, repair material, molds for vulcanizing and in most cases a service car for emergency calls, for it must be remembered that the pneumatic tire is apt to fail when distant from its base and it cannot be driven home flat. Broadly speaking, to give service means doing whatever is necessary to keep tires in fit running condition. Specifically, it may be divided into three divisions: (*a*) inflation; (*b*) changes and renewals, including adjustments, and (*c*) repairs.

It can be said without fear of contradiction that the tire companies themselves are not as yet prepared to give really efficient service in all parts of the country. In fact, even in the principal cities this phase of the business has not been fully developed. In the smaller towns there are almost no air-tanks or pumps to keep tires properly inflated. Pumps on trucks themselves are reported as not always dependable, sometimes requiring from 15 to 30 min. to secure the desired tire-inflation pressure. Some truck operators have ventured to use pneumatic tires even though they have no pump equipment. One such operator uses a hand pump to put in 60 to 70 lb. per sq. in. air pressure. This allows the truck to be driven slowly to the nearest power pump with sufficient capacity to get the necessary pressure. A second, who has no air-pump on his truck, says he cannot afford to carry spare tires because they use too much space. If caught on a long country trip, he waits until a service car arrives and provides proper tire inflation. Another operator who has a large truck fleet equipped with pneumatic tires keeps a light service car continuously busy carrying tires or compressed air to trucks experiencing tire trouble. A fourth encountered trouble with his demountable tire equipment which he had for a long time carried under heavy inflation. It had then become smaller in inside diameter and could not be put upon the rim. The need for rust-proofing rim parts to facilitate changing has been pointed out to the

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tire manufacturers. It has also been suggested that if possible the tires should be made lighter in weight as the larger sizes are very difficult and awkward to handle.

Tire Repairs

By far the most serious and difficult phase of giving service with heavy-duty pneumatic tires, and that which causes the most concern to truck operators, is connected with their repair. In fact, the chief complaint in regard to pneumatic truck tires, aside from their high initial cost, is that they are subject to injuries, cuts and damage, generally of such a nature that they cannot be repaired except at the factory where they were made or, in a few cities, at a factory branch; often they are damaged beyond repair. This is not only expensive but frequently necessitates the purchase of more than one set of spare tires should the first set be injured while the others are being repaired. A tire of 7-in. section or larger, if run flat, is likely to be ruined beyond repair. In more than a dozen cities operators have said that the principal cost of punctures or blowouts is caused by the necessity of laying up trucks awaiting new tires due to stock shortage, or on account of sending the damaged tires to the nearest factory branch for repair. While repair-mold equipment has been ordered for large-section tires, the heavy demand on the part of the tire factories for new molds of all sizes and the difficulty of producing them has made deliveries very slow.

In nearly every city the large tubes can be repaired locally, but the casings have to be shipped away, the truck operator paying either freight or express charges in both directions. Moreover, it is frequently reported that repaired casings deliver but small mileage due to the over-cure of the joined portions. This danger is more difficult to overcome in large-section tires, due to the longer cure required to vulcanize the interior portions of the new part of the casing. No doubt this feature will ultimately be corrected. The tread seems to give less trouble than the side-walls, which are more susceptible to rut wear and overloading abuse.

Because so few service stations are as yet equipped to handle repairs on heavy-duty tires, dependable cost figures are not at present available. In fact, where stocks are available "adjustment" exchanges have usually been made instead of repairs. Of all the causes of dissatisfaction reported for changing back to solid after

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using pneumatic tires, the most numerous have been those brought about by the delays and expense incident to their repair, including additional spare-tire cost and truck hire while waiting for the return of the damaged tires. Such disadvantages are inevitable in a new development such as the one under discussion but, so far as imperfect service features are concerned, they are being overcome as rapidly as possible. In the meantime, truck engineers, salesmen and operators should not condemn the movement toward the use of pneumatic tires, for undoubtedly it will be the means of increasing the scope of usefulness of motor transportation.

Having thus reviewed the advantages claimed for pneumatic tires on trucks in the debatable field and having specified some of their relative disadvantages, I can say that, in my judgment, the question is too new to be decided theoretically or from such meager records as are now available.

Specific Considerations

What general conclusions will guide the operator in the selection of the most satisfactory and economical equipment for his particular installation? So far as I know none have been formulated and given publicity. In this connection, however, I suggest that, in the present state of development, the field for each type of tire may be separated into three classifications, within one of which the operator can reasonably locate his requirements and decide upon his equipment. These three groups are

(1) The imperative field
(2) The economic field
(3) The optional field

The factors that would bring a truck within the first classification for solid tires are (*a*) If it travels over pavements not necessarily good, but having a reasonably hard road surface to provide traction; (*b*) if the delivery must positively reach its destination without fail, at a promised time; (*c*) if the delivery must be made regularly on a given schedule in which the regularity is a more important factor than either speed or cost of delivery, and (*d*) if it carries heavy loads with frequent overloads beyond the rated capacity of the tires.

Similarly the factors that would bring a truck within the imperative field for pneumatic tires are some com-

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bination of the following: (*a*) If it travels over surfaces on which traction cannot be obtained by solid tires, and when the need for traction is such as to outweigh the item of cost; (*b*) if the need for speed of delivery is more important than its cost, and (*c*) if the merchandise carried is so perishable or fragile that it must be protected from road shocks, even at high cost.

The factors that would bring a truck within the economic field for solid tires are (*a*) Short hauls in cities where speed is relatively unimportant, (*b*) heavy loads with a tendency to overload, (*c*) traffic congestion which reduces average speed, (*d*) loading and unloading delays and (*e*) need for low delivery cost.

Similarly the factors that would bring a truck within the economic field for pneumatic tires are (*a*) Road conditions which will not prematurely destroy the tires, (*b*) long hauls, (*c*) high average speed, (*d*) relatively light loads with no overloads, (*e*) good tire-service conditions and (*f*) low cost subordinated to quick service.

In analyzing the economic field, the operator must first decide whether or not he can avail himself of the potential speed pneumatic tires would give. This, of course, includes possible delays due to tire trouble as a result of bad road conditions and provided the local tire-service conditions cannot be depended upon. Next, the features of his service provided by pneumatic tires must justify their extra cost.

The distinction between the economic and the optional fields is difficult to make. In fact, the decision as to which is the better equipment may be purely a matter of personal opinion, without strong factors on either side. Hence I shall not attempt to define them.

One of the most interesting and significant developments which I have noticed is the growing tendency among truck operators to use pneumatic tires on front wheels where the need for protection from vibration is the greatest and solid tires on the rear to carry the burden of the load. This practice has much to commend it, and should steadily grow in favor. Another tendency is toward the use of some type of cushion or non-rigid wheel which, although equipped with solid tires, provides extra resilience through their peculiar construction. There seems to be a very large field in which such wheels can be used both economically and advantageously from the standpoint of improved service.

Designing engineers should study to develop cushion-

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ing effects that may be possible through other means than tires, such as cushion wheels, improved springs, shock-absorbers and the like. While no mechanical device is so resilient as air, much progress must be made before the difficulties are overcome of making air serve acceptably in puncture and fool-proof rubber tires, although the industry is making notable improvement in this direction. Finally, all truck operators should keep account of costs, so that intelligent comparisons can be made. In my judgment, the easiest and most effective way to do this so that all records may be readily comparable, is to use the National Standard Truck-Cost System. Thus, if they select tire equipment after a careful analysis of the peculiar conditions surrounding their problems and keep careful and accurate records of operating costs, they can reasonably expect to eliminate many of the annoying uncertainties of their delivery systems and place their tire installations upon a really scientific basis. [The discussion of this paper is printed on page 728.]

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ADDRESSES AT AKRON DINNER

In connection with the joint meeting of the Cleveland and Detroit Sections which was held at Akron, Ohio, the members attending were given a dinner by the Goodyear Tire & Rubber Co. in its general office building. P. W. Litchfield and F. A. Seiberling, vice-president and factory manager, and president respectively of the company, made addresses.

ADDRESS OF P W LITCHFIELD

The progress of civilization in any country is dependent upon its religion, education, form of government, natural resources and transportation systems. The transportation systems of a country have a very important part in broadening the education of the country, and also in developing its natural resources. As an illustration of that I will briefly review the history of the rise and fall of nations as a corollary to their transportation systems.

The first transportation was by walking. Man never traveled very far then and each little group was almost isolated from other groups. Then came transportation by domestic animals, bringing forward Egypt, Babylonia and Persia. The new transportation aboard boats brought Greece to the front, and larger boats advanced Rome, which was the first nation to start inland again by building good roads, making transportation by domestic animals more efficient. Then followed the sailing ship. Those who first took advantage of that became the leading nations. The cities of Genoa and Venice had then the largest sailing ships in transportation outside of inland waterways, such as the Mediterranean and Red Sea. Transportation over the ocean made England and Spain conspicuous as world powers, and they so remained until the beginning of the nineteenth century, when the steam engine was invented. This brought forward countries which did not have so large a sea-coast but more internal territory to develop, such as our own country. Affairs so remained until our day, when the development of the internal-combustion engine and the pneumatic tire

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made possible the automobile, now the form of transportation that has partly taken the lead.

I will first mention the relative merits of the solid and the pneumatic tire on motor vehicles. First we had the bicycle with a steel tire; then with a solid and then with a pneumatic tire. People said that the pneumatic tire would not do because it punctured and because it cost more. That, however, was no reason why the bicycle should continue on solid tires. Pneumatic tires gave the bicycle a greater usefulness that alone was sufficient for the change. The carriage followed. The development of the pneumatic tire practically eliminated the horse, on account of the speed of transportation by the passenger automobile. Today, many more passengers per mile are carried by automobiles than by rail transportation.

The transportation of merchandise did not follow rapidly the transportation of passengers. When it did follow, trucks were equipped with solid tires. In spite of the fact that every other vehicle had changed from solid to pneumatic tires, after a very short period, there seemed to be a general impression that while this was true of almost everything else, it did not apply to the truck. Many people contended that the truck was the logical field for the solid tire and that the pneumatic tire had no place there. It is possible, in fact probable, that the reason the solid tire maintained such headway on the truck is that the pneumatic-tire development did not keep pace with the development of the truck. We now know that with the introduction of cord instead of fabric in tire construction, the limit of successful pneumatic tires must not be loads carried by the ordinary 4½-in. touring-car tire, but increase up to 12-in. and probably larger sizes.

So long as the automobile was developed only to the extent of replacing the horse-drawn carriage, the automobile industry did not grow beyond that volume. As the automobile was developed further and further, it became so efficient that it created for itself a need and established an industry many times larger than that which it was designed to replace. This was accomplished by the pneumatic tire.

The truck industry is in exactly the same position as the passenger car was. It is at present equipped with solid tires. Practically, it has only replaced the horse-drawn truck, but the efficiency of the truck when properly designed for and equipped with pneumatic tires will

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increase its field of usefulness in transportation of merchandise in the same proportion that the passenger automobile increased traffic volume over that of the carriage which it replaced.

The Obsolescent City Street Car

I shall now discuss the problem of street railway transportation. My first lesson in physics was that two bodies cannot occupy the same space at the same time. You have only to go into any crowded city to see what is happening to the city transportation system when the automobile and the street car try to occupy the same space at the same time. One or the other must go. It was a practical thing, when the streets were not crowded, to place two rails along the center of the street and transport the bulk of the people in cars run on those rails. The speed was good and the cars interfered with nothing in particular. But with the advent of the automobile we find a very different situation. The streets are now crowded, and this condition will get steadily worse and cannot be made better so long as both forms of transportation try to occupy them. It is really ridiculous that one person, in a crowded thoroughfare occupied by thousands hurrying from one place to get to another, can step out of a street car into the middle of the street and stop everything for two or three blocks while he walks through the intervening space to get to the sidewalk. It is not the number of vehicles that can get through a street abreast, it is the time that those vehicles are occupying that street. If traffic can be kept in motion instead of being continually stopped, the same amount of people and the same number of vehicles can go through that street in a third of the time, or, three times as many vehicles can go through it in the same time. Therefore, it will be necessary in the future to provide a transportation system in which the only vehicle that stops is the one that wants to stop, while everything else goes on, and that vehicle must stop at the curb.

It is quite evident that it is the street car that must go. Cities cannot afford to widen their streets indiscriminately or put in more streets; there is too much fixed investment. What they must do is to eliminate one form of transportation by giving another the right-of-way on the streets. I do not know how long it will take us to learn this lesson, but it must be learned. It is being

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carried in other places. The streets of London are narrow and crooked, yet they are carrying more transportation than any streets in any of our own cities, because they realize that there must be no rails in the streets and because traffic is continually moving. There are no hold-ups, no vehicles stop except the vehicle which it is desired to stop, and it stops at the curb. Their ever-increasing suburban population is cared for by placing their street cars underground, so that practically the only people who use street-car transportation are those who come from long distances. The minute these cars come into a congested district they are put underground where they can proceed without interruption and thus permit the traffic on the streets to proceed without interruption. That is the principal reason we can say that, by the law of the survival of the fittest, the automobile must of necessity drive the street car off the streets and that motor-driven vehicles must be provided to take its place.

Almost all growing cities are hampered in their development because the street-car systems have to make expensive extensions involving large outlays of capital to reach out and care for the outlying districts. Population is concentrated and the natural expansion of the city is prevented, resulting in extremely high rentals in the center of the city and relatively cheap land just a short distance outside. Street-railway systems have reached the point where they cannot compete successfully with the automobile, to the extent of making their extensions and getting franchises which enable them to operate at a profit. The result is that there is practically no extension of street-car lines. If they raise their fares they become less and less competitors of the automobile, because the automobile then more keenly cuts into their traffic. They are not measuring up to the needs of the cities and I venture to make the prediction that never again will street-car companies be able to operate at a profit and give satisfactory service on crowded streets in thriving communities.

We formerly heard about the efficiency of rail transportation. We had single-track lines and then, as more traffic came upon them, the speed was reduced and they became inefficient because one car could not pass another coming in the opposite direction. One car had to go off to one side and wait while another came down the line. Then, as congestion became greater, they put in two tracks so that cars could pass without interfering with

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one another. As more and more traffic went over the streets, when one car wanted to stop it did not stop the cars coming from the other direction, but it did stop the cars coming behind it. That is the condition we find today. Now that traffic is so much more congested, we must see to it that a vehicle does not stop a vehicle coming in either direction. In other words, we have to get away from line transportation and take advantage of the whole surface. That means the motor truck; and nothing can stop the transition to this from the two-rail street-car traffic on the street, because every economic need of the city demands it, and the service which must be given can be given only by the motor-driven vehicle. The street car still has one advantage over the ordinary form of automobile for this service, and that is its size. With a smaller number of people in the vehicle the operating expense of a driver and conductor is, of course, greater per person. The problem which engineers must work out to accomplish the introduction of the motor bus on the streets is to design passenger-carrying vehicles of larger capacity than those which are now common.

I think it would even pay in many cities if the street-car companies themselves would take their cars off the streets and substitute motor buses, still using their organization and terminal facilities. They would be able to make extensions and get the traffic which is now going to the automobile. In many cases their power equipments are now inadequate. They could well utilize all the power they are making for the necessary extensions of light and power for the community to take up all the surplus which they would have when the street cars are taken off.

In regard to interurban traffic, what advantage has the motor bus over the street car? Naturally, so far as speed and congestion are concerned, the same crying need of a change does not apply. But there again we have the necessity of going to a large capital expenditure for roadbeds and tracks, and it is difficult to see how that money can be raised, and how it is justified by the relatively small amount of passenger service. The result is that in many cases they do not expand and, because there is no adequate transportation, part of the country is not built up anywhere near as fast as it would have been had there been a transportation system for it. The motor vehicle can accomplish this. It can go outside the city; it does not need a perfect roadbed; it can operate over

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many roads as they now exist, while the street car cannot. Automobiles can go out and pick up the traffic at a profit. When they begin running over the line and transportation is established, more people go to live along it because they have some means of getting back and forth. The business builds up by taking the population to the places where the motor truck first went. There is first no need of transportation, because there are no people; but the motor bus goes out and supplies transportation, and people follow. That creates the demand and the volume of business which makes an ever-increasing number of motor buses necessary. As more and more people go out, and become more and more scattered, longer hauls and more and more transportation are required, not only to take people back and forth but to get their supplies to them.

We often hear that the cost of transportation is much higher outside than it is inside a city. People talk about the five-cent fare in the city and add ten, fifteen or twenty cents to go outside on the motor bus, but they do not stop to realize that it is because the street cars and the transportation are good only in the city that rents are very high, and the cost of living is on that account very high in the city. The extra cost of fifteen or twenty cents which they pay for transportation by a motor bus, is more than equalized by the better living conditions obtained for lower rents when they go out further. While they are actually paying more for transportation, they are more than saving it somewhere else.

The Pneumatic-Tired Truck

As to the possibilities of the pneumatic-tired truck for combined railroad and truck haulage, and of the long-distance truck to replace traffic now handled entirely by the railroads, I think that it is along these lines that the greatest future for the motor truck lies. This is possibly not because it will mean so many more trucks in numbers, but because the volume of the truck business depends upon tons per mile carried. Larger loads and the longer distances make possible an enormous increase in the volume of the motor truck business. The use of the motor truck for such service as this is limited to very narrow fields when we use solid tires, because we cannot get the speed or the carrying capacity that we can get with pneumatic tires. To take care of this service suc-

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cessfully, we must use much larger units. We have used the 3 and 5-ton truck, and are now in the stage where we are rapidly changing over to pneumatic equipment on 3-ton sizes. What shall we do when we go above this? It was largely to find out what to do that we started the Akron-to-Boston Express, somewhat in advance of its economic practicability, to try to overshoot the mark rather than to grow up by easy stages; to find out quickly by actual experience what the weaknesses were, and how to overcome them. We learned several things. Incidentally we found it one of the best tire-testing experiments we ever made. We learned also that while it is not particularly difficult to make 12, possibly 15, perhaps 20-in. tires, it is probably questionable whether they are the tires to make for this kind of service. There is a certain limit to the outside diameter of a tire with reference to its cross-section. We began to find out when we got up to 10 and 12-ton trucks that we might possibly have to load them from second-story windows, because the center of gravity and the truck body were so high that we could not keep down to proper proportions for ordinary service. So we figured on what to do to offset that condition; to keep the center of gravity and the truck body lower. It seemed logical that the only thing to be done was to use multiple wheels.

It is just as foolish to try insistently to increase carrying capacity on four wheels in an automobile, as it is to attempt to do so on a railroad coach. The little four-wheel railroad cars in Europe have practically never gone above 10 tons' capacity, while by multiplying the number of wheels we build our own freight cars up to 50 tons' capacity. The same thing is true for the motor truck. I think we will find that the solution of the problem of the practical pneumatic-tired truck above 3 tons is to use multiple wheels, that is more than four, say six wheels. We finally had to experiment and build trucks ourselves. We are quite satisfied that the truck must be on tandem wheels and not on twin tires on the same wheel. The riding quality and carrying conditions will be better; and we will get better traction. By putting the extra wheels underneath the rear end of the truck body, we can avoid that damage to tires which we get with large single tires, because the tires are twisted and distorted with a big body overhang. We also get additional traction with a four-wheel drive. While the particular design or method may vary, we wish to express

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the belief that the motor truck with multiple wheels is the thing with which to accomplish the building of the larger vehicle, to replace street cars in the cities and for long-distance hauling to replace freight cars.

The average mileage limit of a freight car is something like 20 per day. That is because, when one freight car is loaded, it cannot move; it stands around and is shoved around waiting for another. When those two get together, they have to wait for another. The service is very slow and not economical. By the introduction of motor service by truck, the unit is due to move when the load is ready to move; it then goes to its destination. The same principle that applies to city traffic, of everything being congested and one car stopping everything else, is what we have in freight service today. Each car is dependent on many others and cannot move until all are ready. The motor truck in that respect will give service, because each truck moves when it is ready and is not stopped or handicapped by the action of any others. We have seen the great part played by the motor truck in transport during the war. It would have been almost impossible to supply properly the armies at the front by the railroad systems, and it was the availability and the quick multiplication of service by motor truck which accomplished the desired result of keeping the Allied armies supplied as they advanced.

Canada, South America and the Orient

Looking toward reconstruction, we know that the railroad systems of Europe are a network and that in the most sparsely-populated countries, South America, Canada and the Orient, there are no railroads. These countries have great natural resources. The European countries have very limited natural resources, based upon their population. The first-mentioned countries have been held back for years because they could not secure the capital necessary to put in railroads, on account of their sparser population. We know that, having roads and automobiles, it is not necessary to go to large capital outlay to provide transportation, and these newer countries will be very greatly benefited by the development of the automobile for passenger and freight carrying, for they can thus acquire the means of transportation. Combined with their natural resources, those countries have a distinct advantage over the European countries. They

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have built up and supported the European countries because Europe's transportation systems were so far advanced that it could manufacture and ship more economically than those countries which actually had the natural resources and the raw materials. The result was that the raw materials went to Europe and came back in the form of finished product. Now the sparsely settled countries are better able, through the automobile, to take care of their own finished products; and they will develop rapidly.

The introduction of the automobile truck and passenger car has reduced to a very large extent the values of the railroads. Their values were a combination of the cost of construction of their facilities, plus a franchise value given them because they had no competition. The introduction of the automobile, giving them real competition and substituting for their form of transportation a better one, has depreciated those franchise values. That is one of the reasons for the difficulty of further railroad financing, and why it will be easier to finance advances in automobile transportation. The peoples of Europe will find this fundamental condition to mean that they cannot go back where they were before, to their previous position of influence, because it will be taken from them by the newer countries on account of their ability to provide for themselves an adequate transportation system, which they could not do before. The tropical countries, for instance, where the population is largest and the natural resources greatest, have this chance, combined with the advantage they have recently gained by the elimination of tropical diseases, such as yellow fever, making it safe for engineers and men of the white race to go there and introduce transportation systems.

It is stated that about 7 per cent of the workers of the United States are employed in transportation and that in China about 50 per cent are so employed. This is because China is deficient in roads and railroads, so that half of the workers must be continually wheeling and carrying things about. According to this, China's poverty is largely due to this necessity for employing a large part of the population in moving produce from place to place. Before China can enjoy a prosperity equal to that of the rest of the world, a great mileage of roads and railroads must be built. At present nearly all Chinese roads are mere foot-paths used by men with wheel-barrows and donkeys. The cost of haulage by this method, even with

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wages at 15 cents per day, is from 4 to 12 cents per ton-mile. That gives an idea why China is so backward in modern civilization, and of what can be accomplished in China, with her 400,000,000 people, by the building of good roads and supplying motor transportation. China has not had railroads because it was too expensive to build them, on account of the enormous outlay necessary for the rails. But they can build roads in small amounts at a time, operate vehicles over them and consistently expand them. The same conditions exist in other places. I think that the war has set such countries fifty years ahead relatively, because capital can be and will be invested in road development there; they will have facilities they were unable to get before. They are the people who are most solvent and can command capital to come to them, because their credit will be best.

Roads and Tires

One other point in regard to the advantages of pneumatic over solid tires in motor transportation. The highways will be public property; they will not be built by private corporations and franchises given in order to encourage private capital to invest in them, as has been necessary in the case of the railroads. They will be built by public capital, but we will find that the cost of the roads will more and more be paid for by the traffic which goes over them, in the form of vehicle taxes which will probably be progressively increased. The initial cost and the upkeep of the roads will vary directly with the loads to be carried and the damage done by the trucks going over them. Suppose two loads are to be carried on 5-ton trucks, one on pneumatic tires and one on solid tires. We know well the difference in the kind of road required to stand up under the solid-tire traffic as against that of pneumatic-tire traffic, and we also know the upkeep cost for the two kinds of traffic. With the heavy motor truck developed on pneumatic tires, it will not take half the expenditure for good roads that it would if those trucks were equipped with solid tires. In other words, the same appropriation would build twice as many roads of a suitable character to carry pneumatic-tired trucks, as to carry solid-tired trucks. And, in the long run, the truck which damages the road most will be taxed in almost direct proportion. I think that the action of the State of New Jersey a year ago is merely a forerunner

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of what must be expected almost universally. This will make it necessary to substitute the pneumatic for the solid tire on all large trucks.

Two years ago we spent most of our time trying to convince people that pneumatic truck tires have merit, that there is some use for them. We are now trying to increase our facilities enough to produce sufficient tires of this type to take care of the demand which has been created. I think that truck designers will find that the pneumatic tire has sold itself on its merits to the public, and that they will have difficulty in designing trucks for pneumatic tires fast enough to take care of the needs and demands of the people. Any truck manufacturer who tries to influence public opinion and build his product along solid-tire lines will find himself in exactly the same position as were the men who said that the automobile would never amount to much. I think that we cannot do anything more valuable to meet the needs of the country today than to forget the design and scrap the material provided for trucks on solid tires if necessary, and devote our energies to the proper designing of a pneumatic-tired truck with the idea that it will be equipped with pneumatic tires only. It appears to us that the volume of business in pneumatic-tired trucks will be many times what it is today in pneumatic-tired passenger vehicles, and our whole development is based upon this. Personally, I think the only limit to the development of the pneumatic-tired truck is the amount of crude rubber and long staple cotton that is available to make the tires.

ADDRESS OF F A SEIBERLING

The greatest and most vital industry in our country is that of agriculture. Allied with it and next in importance is that of transportation. For seventy years the railroad was the dominant factor in the needs of transportation in our country, but in the past twenty years there has come the motor-driven truck, which is now in process of evolution, and which in my judgment will result in a revolution in the transportation of the world's goods. It is less than twenty years ago that we made the first pneumatic tire. We started twenty-one years ago to make bicycle tires and solid carriage tires; very shortly thereafter we commenced making pneumatic tires for small runabouts. The type then produced was the single-tube tire, with little studs in the base fastened by bolts

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at four points through the rim. It served very well on light vehicles. Then came the electric motor buses, first appearing in New York on Fifth Avenue. The best tire that could be devised for them was that same single-tube pneumatic with the four studs through the base of the rim, held by plates in the base of the tire. It would take a long story to relate the difficulties we and other manufacturers suffered in the effort to put pneumatic tires on these motor buses. They were an utter failure. Out of it, however, came the natural evolution through the pneumatic tire with the inner tube, until we arrived at the state we are now in. We demonstrated that we could carry considerable weight on pneumatic tires with single inner tubes, but there was a limitation largely due to weight and speed.

When we began to develop cord tires, we were dealing with a new principle of construction; we have more than doubled the weight-carrying capacity, with higher speed and less heat. We realized five years ago the evolution that is now under way. Some of us believed, and still believe, that the ultimate tire is the cord tire and that there will be no fabric tire, much less any solid tires on moving vehicles. We believe that so firmly that most of our engineering force is employed on the development of the cord tire.

The world views the development of the motor vehicle and the tires that have come along with it in the past twenty years as a marvelous thing; it has been. No page of history has been brighter in mechanics than the progress in automobile manufacturing in the last twenty years, but I still believe we are largely in our infancy in the matter of transportation. When I make that statement I must connect with it development other than the developments you will make and developments we will make, because they are largely traveling parallel. I must take into consideration what I believe is coming in the development of our highway systems.

Future Highways

We have over 2,000,000 miles of roads in this country. We are commencing to dignify them with a higher term, highways. Out of those 2,000,000 miles, less than 200,000 are what can be called improved. Such improvement as they have will be called negligible ten years from now. They are inadequate. The development of the

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motor truck is much beyond them. We must get a new vision of the highways. That vision will carry us to the highway with a solid foundation and hard surface; one adequate to carry at least a 5-ton per wheel load for truck service, and wide enough for the traffic of high-speed vehicles without danger. We will have no more 12, 14 or 18-foot highways, except in sparsely-settled districts. We are surely coming to the solid-foundation road, adequately drained.

It appears to me that you who have the destiny of motor-truck development largely in your hands must see the future; you must have the vision of the final thing, as near as you can get it. It would be a simple thing for you to design the ultimate car if you knew that ten years from now every highway built in the United States would be solid, substantial and smooth, and that you could put under it tires that would carry any load you would give it. I am referring now to the pneumatic tire. If you knew all that, you would design a truck or a car entirely different from the ones you now design. In my judgment we are working to that end with certainty.

Progress in Design

One of our engineers brought in the design of a six-wheel truck, the ultimate truck, along that line. I of course laughed inwardly, but I let him talk. He took me out on the hills one day over our rough roads with this truck and I was utterly dazed at the way it operated. I saw in that idea a start that meant less weight in the truck, less cost and higher service; largely as a result of the development of the pneumatic cord tire. The compensation of the leverages of the turning mechanism, the fifth wheel, etc., is largely provided in the swing of the pneumatic tire.

We spend hundreds of thousands of dollars experimentally, and a majority of it is wasted, but now and then we get something that is worth all that we have wasted ten times over. You inventors and designers know that the progress of the world has been made only along that line and that it must be done. When you have developed something entirely new, you have achieved something. You have rendered a new service to mankind, and that is the great joy of men who are doing constructive things and making progress.

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In China there are 400,000,000 people; it is a country larger than this country and has a railroad mileage of 1 to 30 of ours and a motor-car service that is negligible, almost confined to the cities of Shanghai and Hong Kong, some 5000 or 6000 cars. Think of that tremendous gap that can be filled and will be filled sometime. Roadways are so narrow that a vehicle could not get through many of them; railroads are almost impossible to build because of Chinese traditions and reverence for the dead. So many have died in China in the centuries before us that nearly every ten square feet contains a grave, and they do not allow railroads to be built over graves. That difficulty of overcoming the prejudice of a people is an enormous one, and it will take centuries to overcome it in China. But they have thousands of miles of post roads, some of them built by the Manchus centuries ago, paved with blocks of stone 3 to 5 ft. long and 10 to 12 in. thick. They are largely in disuse. Time has covered them and they are worn to some extent, but it struck me immediately that there is the foundation for a good road. With a surface of the kind we could build, with drainage systems along the side, we could make a good road at nominal cost, for labor in China is very cheap.

None of us has visualized China for automobiles or automobile tires, but I believe that within our lives we will find motor cars running over Chinese roads. We will find that that great mass of people will some day awaken by virtue of American and European enterprise and start road-building in good solid fashion. When they build a road from Tientsin to Pekin as an experiment in a hard-surface road, motor cars will be there the moment it is built, and we will have a new market. After that has been done, other roads will be built and the post roads will furnish the means of transportation that they have been thinking of as applicable only to railroads. I think it is going to be very difficult to get money for suitable railroads in China. This will not be necessary if they build roads there suitable for motor cars such as we have in this country.

Predicted Exit of Solid Tire

We look to you S. A. E. members to work along with us in building the ideal truck for the service of this country. We are thoroughly convinced that three years from now the solid tire will be dead as applied to truck service.

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We believe that the cord tire we are now making is only the starting point of the finished product that will be in use five years from now. We are refining and improving all the while, doing everything we can to meet the situation. We believe we will make progress. Forget the solid tire and think only of the pneumatic as adequate to every need, for it will carry the heaviest loads as well as the lightest, and carry the high-speed trucks which the hard tire cannot. The solid tire is almost as bad as the iron tire in destroying the roads. The pneumatic tire absorbs all the shocks.

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BUFFALO SECTION PAPERS

JAPANNING PRACTICE

By W A Darrah[1]

An analysis of japanning practice as a systematized industrial operation is presented as the result of an investigation. The nature of japans is discussed and an outline given of how the apparently contradictory requirements that japans must be weatherproof, somewhat flexible, sufficiently thick to be lasting, possess enough hardness to prevent excessive scratching under ordinary service conditions and take on a brilliant finish, can be fulfilled in an ordinary industrial plant without undue expenditure, so as to accomplish the original and primary objects of applying a finish to metal parts to prevent them from too great deterioration and supply a pleasing appearance to the finished product.

Adequate provision for securing a uniform product is essential. The details of this are discussed. Three ways of applying japan are explained. The considerations involved in cleaning the metal and baking japan are enumerated at some length and the methods are described. Japanning plant equipment, including japan storage and handling, a mechanical conveyor, cleaning and baking apparatus, is then commented upon at length, the thought then passing to a detailed consideration of heating methods. This is followed by data and discussion regarding the temperature control and mechanical construction of japanning ovens.

The japanning operation is one of the most important from the standpoint of finish and appearance, but it is one of the few operations which the average automobile manufacturer still carries out on a rule-of-thumb basis, trusting to traditions that the result will be satisfactory. Possibly the combination of chemical engineering, heat application and mechanical problems, has caused this condition. With the thought that an analysis of japanning practice as a systematized industrial operation may work to the improvement of the commercial product, the investigation described herein was made.

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The lack of definite knowledge regarding japanning practice frequently begins with the manufacturer. In spite of the fact that excellent finishes are now available, many manufacturers are following formulas which in some cases are over a generation old. The average commercial japan usually comprises the following ingredients:

(1) Linseed or other oxidizing oil
(2) Gums or pitches
(3) Drier
(4) Color
(5) Solvent

Fundamentally the average japan consists of a drying oil, which forms most of the body and serves as a medium to impart flexibility to the finished coating. Linseed oil is most commonly used for this purpose, although other drying oils may be employed with the proper precaution. Incidentally, the basic cost is controlled by the quantity of linseed oil employed; the durability and protection are also dependent upon the amount and grade of this ingredient. The presence of an excess of linseed oil has a tendency to make the finish less brilliant than normal, but gives a thicker coat and greater durability; the surface is also somewhat softer and loses its polish more readily, although the protection to the metal is good. On the other hand, too little linseed oil is usually compensated for by the addition of more gums or pitches, in which case the tendency of the japan is to be rather hard and brittle; but the finish is very brilliant. Therefore, the cheaper finishes are likely to be more brilliant than the higher-grade products, but the coating is thin and cracks off with comparative ease, and the protection to the metal beneath is imperfect.

In some cases rubber has been substituted for linseed oil in certain japans, particularly those employed for the first or priming coat. At the present market prices very little rubber is used. It appears that rubber acts in substantially the same manner as linseed oil except that it does not give the smooth finish common to oil. The function of the oil or rubber is to act as a flexible binder and supply the protection to the metal surface, while the gums and pitches serve to give hardness and brilliance to the finish.

Most baking enamels are black or very dark colored

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on account of the great difficulty of applying and baking a light-colored enamel quickly. Even under the most careful handling, the lighter-colored finishes have a decided tendency to turn yellow or brown. Fading is a common occurrence with most colored baking japans, and the final result is generally unsatisfactory. Carbon black is employed with excellent results in the priming coat of many of the black japans. Aside from the relatively small use of black pitches or gums, carbon black is the most-used coloring material.

Driers are frequently added to commercial japans, but this practice is not to be entirely recommended. The nature and amount of drier employed are of fundamental importance, as any substance which may be subsequently attacked by moisture and air must be avoided. The organic driers are probably the least harmful. It should be noted that the conditions under which japans are usually baked are such as to reduce materially the necessity for a drier. The solvent generally employed is either benzine or solvent naphtha. Benzine is preferred, although both materials merely act as a thinning medium and permit the mechanical application of the japan with greater uniformity and with minimum labor. The solvents are, of course, entirely removed in the drying and baking operation, and it appears that they do not combine in any way with the materials of the japan. As a rule, commercial japans carry about 50 per cent by volume of solvent. It is not unusual to add 15 to 30 per cent solvent at the enamelling plant to facilitate handling and application. The exact viscosity of a japan can be controlled absolutely by the amount of solvent, assuming that measurements are made at a constant temperature, and this is a point of vital importance from the standpoint of securing a uniform product. It is impracticable to advise the best viscosity to employ without full knowledge of all the conditions under which the japan will be used, as well as of the grade of product desired.

The matter of purchasing japan is at present surrounded with much mystery. General appearances and characteristics will tell almost nothing about the quality. A trial application and a test of the resulting enameled surface is a successful and reasonable basis for selecting japans, but it should be kept in mind that the means of application and conditions of baking have an extremely important bearing upon the appearance and durability of the product; an excellent japan may give inferior re-

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sults when not handled in the best manner. It has been my experience that most japan manufacturers are conscientious in their endeavor to supply a good grade of product. Unfortunately, competitive conditions are such that the price which the consumer wishes to pay is determined, and a japan representing the best grade available for that price is submitted. The ingredient which has the most influence in determining the selling price and quality is linseed oil. In many cases the higher quality japans contain more expensive gums, while the cheaper japans may contain even shellac and stearine pitch.

To decide intelligently upon the best grade of japan and the best method of applying and handling the material a brief consideration of the function of japan is desirable. The original and primary objects of applying a finish to the metal parts were to protect them from excessive deterioration and supply a pleasing appearance to the finished article. To realize these conditions in practice the japan must be weatherproof, somewhat flexible, sufficiently thick to be lasting, have sufficient hardness to prevent excessive scratching under ordinary service conditions and take on a brilliant finish. I will attempt to indicate how these somewhat contradictory requirements can be fulfilled in an ordinary industrial plant without excessive expenditure of money.

Handling Japan

A fundamental requirement of any plant using large quantities of japan is adequate provision for securing a uniform product. As a rule the japan manufacturer is able to supply a uniform product initially, so that the user can confine his attention, aside from the ordinary inspection laboratory tests on purchasing, to the equipment designed to maintain the product constant throughout his own operations. Most systems, whether they be of the dipping, spraying or flowing type, will require large storage capacity for mixed japan, that is, japan plus solvent, and also adequate tankage for mixing the material in use with additional solvent to maintain the viscosity standard. It is very desirable to maintain a uniform temperature throughout the rooms where the japan is handled or mixed. Uniformity is the essential feature, but the best results appear to be secured when the temperatures range from 80 to 100 deg. fahr. Obviously the higher the temperature of the japan the

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smaller amount of solvent required to secure a given viscosity. On the other hand, if the temperatures of the room and the japan are too high, the solvent has more tendencey to evaporate.

Another consideration of prime importance is to agitate the japan in all parts of the system continually. Even the highest grade product has a decided tendency to deposit some of the heavier ingredients after standing. One engineering means of reducing the trouble from this cause is to avoid the presence of pockets or undrained pools of japan in any part of the piping or tankage system. Entering pipes should end near the top of the tanks and exit pipes should be connected to the lowest portion. All tanks should, of course, be covered wherever feasible, and expose a minimum surface to the atmosphere in case it is impracticable to cover them. Lights and flame should obviously be kept very far distant from all japan equipment. The most satisfactory method of agitating large quanties of japan usually involves a circulating system, including circulating pumps, lawns or strainers, mixing tanks equipped with agitating means and a piping system which should be provided with heat insulation in case the pipes pass through rooms having a lower temperature than that at which the japan is maintained. The mixing and storage tanks should be equipped with some means such as hot-water pipes for maintaining the temperature constant, although this precaution is not always essential if the temperature of the entire room is thermostatically controlled.

Japan is usually applied in one of three ways. Small articles such as automobile fenders can be dipped directly in the tank of flowing japan and after a period of dripping can be carried by conveyors into the baking oven. Large surfaces which cannot be conveniently dipped can be coated by flowing. In this case the japan is pumped through a hose and out of an elongated slotted nozzle, in such a manner that it flows smoothly and regularly over a considerable surface. The method of application, when properly handled, results in an excellent finish and is applicable to automobile bodies and similar parts. A third method, also used for applying paints, consists in spraying the coating material by a stream of compressed air. This method, when properly employed, produces good results and also permits some control of the thickness of the coat. The application of japan by spraying is, however, attended by serious personal inconvenience, due

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to the unpleasant vapors which invariably result; for this reason labor is relatively expensive and difficult to handle. Some attempts have been made to produce an automatic spray or mist so arranged that the article to be treated passes through a closed chamber on a conveyor and under these conditions is entirely coated with paint or japan. Control of the speed of travel of the part to be coated offers a rough means of controlling the thickness of the coat. The spraying method is probably more frequently employed in connection with the painting of chassis and similar parts which do not require a high grade of finish.

The amount of japan which adheres to a freshly coated surface is naturally a variable, depending upon the viscosity of the japan, the condition of the surface and some other factors. It is therefore impossible to make a general statement which will cover all cases, but some instances resulting from actual experience may be helpful. For example, in enameling such materials as front guards, mud aprons, runabout shields and tanks, actual practice indicated a consumption of 1 lb. of liquid japan to each 50 lb. of sheet metal enameled. The metal in this case was naturally a variable ranging from 12 to 18 gage. In another case, in which japan is applied by flowing to one side of the surface only, an average of about 1 lb. of japan to 180 lb. of metal is employed. Here the average thickness of the entire surface averaged about 14 gage metal. As an average, it would seem that about 25 sq. ft. of surface can be covered by 1 lb. of japan in one coat, although, as already pointed out, this quantity is so closely related to innumerable variables that only an approximate estimate can be made. In case a primer coat is applied to the metal, average practice indicates that about 30 per cent additional weight of japan will be required. In other words, because of the numerous crevices which must be filled, the first or priming coat requires an average of about 1.3 lb. of japan for each 25 sq. ft.

It should be understood that the figure of 1 lb. of japan for each 25 sq. ft. of surface applies to the dried japan, as is also the case with the value given for the first or priming coat. The weight of wet or liquid japan, which adheres to 25 sq. ft. of surface, will approach 3 lb. After dripping, the loss in weight by this operation will average about 1.75 lb., while the remainder of the loss in weight results from the evaporation of the solvents during the drying operation. In case the primer coat is sanded before the application of the finish coat, the weight

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of dry japan removed is about 0.5 lb. per 25 sq. ft. of surface. As a rule spraying japan weighs about 7 lb. per gal., while the spraying paint used on chassis and similar parts will weigh about 9 lb. per gal. From the data and information given above it is possible to calculate accurately the quantities of japan required for a given production and the data, in connection with the figures given for the circulation required, will permit fairly accurate design of the japan-handling equipment. The speeds allowable for the travel of japan through pipes and conduits should somewhat exceed the safe speeds for the flow of oil.

The explosive nature of a mixture of air and the solvent used in japan necessitates a careful study of the air circulation system, wherever japan is employed. As a rule, the danger limits lie between 2.4 and 6.1 per cent of the weight of the solvent in pounds. In other words, a mixture of 100 lb. of air and 3 lb. of evaporated solvent is extremely dangerous. Many disastrous explosions resulted in the early days of japanning due to ignorance of this condition. It is good practice to maintain the maximum concentration of benzine solvent in air at less than 1 per cent by weight, as under these conditions explosions are practically impossible. The basis given of calculating the necessary amount of air circulation is in my opinion much more logical than the empirical method frequently employed of assuming either a given number of changes of air per hour or a given number of cubic feet of air per pound of material japanned. The misleading results which the latter method may involve will be clear when a comparison is made on this basis of the air circulation required for japanning engine flywheels and automobile fenders.

Cleaning the Metal and Baking Japan

It is good practice to thoroughly clean the metal surface before applying the japan coating. While this subject should logically precede the discussion of the application of japan, because of its connection with ovens and heat treatment, it seems better to include it at this point. It is, of course, evident that when the metal surfaces leave the presses and the assembly room, they will be covered with a large amount of grease and other organic impurities resulting from shaping and handling. If this material is not removed the japan will not adhere uni-

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formly, and the appearance will be very unsatisfactory. Two methods are used in practice to remove the oil and grease. One consists in washing the surface with gasoline or other solvent. This is usually quite effective, but as a rule requires more labor and greater care. It is not automatic and depends to some extent upon the care taken by the operator. It also involves very serious fire hazards, by reason of the explosive gasoline vapors evolved in the drying process, and also because of the large exposed tank of gasoline which is necessary. The danger of striking sparks either by friction or from electrostatic causes, as well as the hazards resulting from electric light and power wires, is considerable. I have investigated this subject somewhat, with a view to adding materials which will largely reduce the fire hazard, and have secured some interesting results.

The second method employed consists in burning off the oils and grease in a hot oven. It has been found that a 15-min. exposure to a temperature of about 500 deg. fahr., in the presence of an excess of air, will entirely remove the oily materials without in any way adversely affecting the surface. Naturally, the condition of the surface, the weight of metal to be treated and many other factors will affect this operation. The data given are based upon sheet metal surfaces averaging about 14 gage. In this case the amount of oils and grease removed averages about 0.3 lb. per 25 sq. ft. of surface. The amount of air employed for circulation, under these conditions, can be determined upon substantially the same basis as that employed in japanning practice. In other words, the concentration of vaporized oils should not exceed 1 per cent by weight of the air employed.

Aside from the matter of compounding the japan, no single factor is so important as the baking process. There are many factors which require careful control to secure a durable, hard, elastic finish, having a good appearance. Some of the more important of these are (*a*) time of baking, (*b*) temperature of baking, (*c*) temperature gradient, (*d*) uniformity of temperature and (*e*) air condition in the oven.

To understand the relations of these factors a brief discussion of the action of the japan during the baking operation will be helpful. After the article to be japanned, such as an automobile fender, has been dipped in japan, the excess of liquid gradually

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flows from the surface by dripping until a fairly uniform condition has been secured. While in this state the fender enters the japanning oven, being preferably carried by an automatic conveyor, and its temperature is gradually increased. The first effect of the increased temperature is to soften the layer of japan somewhat because the heat has a tendency to lower the viscosity. In case there are any pores in the coating, this action allows them to be filled up. It also results in reducing the thickness of the coat, with the natural consequence that its durability is somewhat reduced. The softening of the surface layer is immediately followed, however, by the evaporation of a portion of the solvent, which in turn tends to harden the japan coating. This action continues throughout the baking period, until the solvent is completely removed. At the same time the linseed oil undergoes a process of polymerization and oxidation, similar to the action in drying paints and varnishes. The presence of a large excess of air is of material assistance in hastening the oxidation process as well as in removing the benzine vapors, and thus hastens the evaporation of the solvent. As the temperature continues to increase, the gums and resins begin to liquify and then to give up certain more volatile constituents in the course of forming a hard condensation product. This is usually the last stage in the hardening of the japan.

It will be evident that the resultant product will have a surface finish depending upon the relative temperature of the japan and the surrounding air. In other words, if the japan and the metal surface upon which it is spread are warmer than the air about it, the polymerization of the oil and the hardening of the gums will take place more or less uniformly throughout the mass, at the same time that the evaporation of the solvent is occurring. Under these conditions the surface will be relatively free from microscopic pits, which are sometimes noticed in poorly handled japan. On the other hand, if the air surrounding the fender is warmer than the metal and japan itself, the surface of the japan will tend to solidify before the interior and even before all of the solvent has been evaporated from the japan layer. One result of this condition is the formation of tiny pores or holes, caused by the evaporating solvent forcing its way through the outer layer or skin. These pores may be microscopic in size but serve as a weak point at which the japan may be attacked by the weather. The pores may also accumulate dust and dirt,

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thus causing the body of the automobile to have a very unsatisfactory appearance after relatively short service.

It is thus seen that a means of heating the articles to be japanned, which permits keeping them slightly warmer than the surrounding air, is desirable. To obtain such a condition wholly, appears to be impracticable for ordinary commercial work, but it can be approximated by supplying as much heat as possible by radiation from hot bodies. In other words, the heating of a japanning oven exclusively by hot air, is not as satisfactory as heating it by radiating surfaces. The most practical compromise, considering both the quality of the product and the cost of operating the oven, lies in supplying by radiation the heat necessary to raise the temperature of the metal and the japan to the desired point, and at the same time heating the entering air to approximately the temperature of the oven. Generally speaking, the lower the maximum temperature employed in baking the japan, the better will be the resultant surface. It will, of course, be evident that a reduction in oven temperatures means an increase in the baking time, which in turn means either a materially larger investment in oven equipment or a corresponding reduced production.

Japan manufacturers urge the lowest possible baking temperature and the longest possible time, speaking, of course, from the standpoint of securing a durable and generally satisfactory finish. On the other hand, because of the ever-increasing production demands, the tendency of the automobile manufacturers has been to increase the temperature and decrease the baking time. Practice is widely variable in this connection. Excellent results are secured with baking temperatures of from 450 to 475 deg. fahr. In some cases temperatures of from 350 to 400 deg. are employed. A temperature of 450 deg. requires a baking period of about 45 min. to secure the best results, although in some cases baking may be completed in a 30-min. period. Temperatures of from 350 to 400 deg. fahr. require a baking time ranging from 4 to 2 hr. to secure the best results, although this may be materially decreased under some conditions. The possibilities which arise in connection with a quick-setting japan are very attractive, and some surprising results have been secured. I have given consideration to japans in which the solvent is water, and the field here disclosed is very large.

Extensive tests, as well as theoretical considerations,

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indicate that the resultant surface will be improved if the baking temperature is increased very gradually. The theoretical basis for this condition follows, of course, from the fact that the solvent will be given ample opportunity to evaporate before polymerization of the oil and the hardening of the gums take place. Several large japanning plants have equipment for "preheating" the material before subjecting it to the final baking. Steam coils operated at temperatures ranging from 250 to 300 deg. fahr. are employed for this purpose. In spite of the theoretical advantages and those shown by tests, it is very doubtful whether the preheating principle is of any practical advantage. In the case of at least one manufacturer, equipment already installed for this purpose is not employed. If preheating is not used, the temperature gradient will be substantially a straight line, increasing rapidly to a maximum at the entering end of the oven, in the case of a continuous equipment, and continuing at the maximum temperature throughout the baking period. It is obvious that uniformity of temperature throughout the oven is of the utmost importance. Lack of uniformity is very likely to result in hard, brittle, over-baked portions, or gummy and soft spots, which will collect dirt and dust as well as show excessive scratching.

It is desirable that the air supplied to japanning ovens should be controlled in some positive manner, as natural ventilation should not be relied upon. It has been the experience of those plants relying upon natural ventilation to maintain the air circulation, that extremely variable results are secured. In these cases the ovens require constant supervision and the rate of production must be decreased to compensate for weather changes. The air used for circulation within the japanning oven, must be relatively free from dust, and as dry as possible. In some plants the precaution of washing the incoming air has been taken, but this does not seem to be necessary under ordinary operating conditions. The advantages of preheating the air to oven temperature will be seen when it is considered that this tends to remove a portion of the lint or dust by burning, and also lower the percentage of saturation.

To secure a high-grade finish it is customary to apply at least one primer or "rubber" coat, followed by from three to four finish coats. The primer coat is usually somewhat thicker than the others and carries most of

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the pigment, carbon black. The treatment, application and baking of the three coats are substantially the same, as regards both time and temperature. The primer coat usually gives a dull or rough finish without hardness or brilliancy; the latter characteristics are supplied by the finish coats.

Japanning Plant Equipment

The japanning plant includes the following essential elements: (*a*) japan storage and handling equipment, (*b*) a mechanical conveyor and (*c*) cleaning and baking equipment. The equipment involved in the storage and handling of the liquid japan has been dealt with briefly in the earlier portion of this paper.

The mechanical conveyor may take many different forms, depending upon the nature of the material to be handled and the desired method of treatment. Each individual plant requires a study of many local factors before a sound recommendation can be made as to the type and the general characteristics of the conveyor. The simplest possible type of equipment should be employed and a special effort should be made to avoid both special designs and complicated mechanism. The fact should be kept constantly in mind that difficulty with the conveyor system will completely tie up the plant until it is corrected, involving not only a loss of production and time, but possibly causing a large amount of defective work. With this in view, the conveyor should be provided with ample factors of safety in all its parts, and present operating practice should be freely considered. The relatively high operating temperatures to which some portions of the conveyor are continuously subjected, should be kept in mind from the standpoints of lubrication, wear and strength. At temperatures in the neighborhood of 450 deg. fahr., most oils are valueless, and babbitt or composition bearings are objectionable. It is also of interest to note that the light from the mercury arc lamp has been found to be peculiarly suited for inspection of japanned surfaces. Experience indicates that the monochromatic nature of light from this source allows ready detection of cracks and imperfections.

The japanning oven is one of the most important parts of the plant equipment, since on the proper operation of this apparatus depend the uniformity and quality of the output. While there are many conflicting requirements

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incidental to the successful operation of japanning ovens, a few of the fundamental considerations are (*a*) safety, (*b*) reliability, (*c*) controllability, (*d*) economy, (*e*) production and (*f*) cleanliness.

Two fundamentally different mechanical arrangements are employed in the construction of japanning ovens, although both types consist merely of a large box, usually of metal, surrounded by from 3 to 6-in. of heat insulation. In the case of the earlier or batch type of oven, the material to be japanned is placed in the oven, the doors are closed and the temperature is raised to the desired point. The heating is continued for the necessary length of time, and usually some means of ventilation is employed. The batch type of oven, when properly operated, will produce excellent results, and is particularly adapted to small plants. Automobile factories producing not more than 100 cars per day can secure excellent results with this type, although it will be evident that continual supervision by skilled and responsible help is necessary. The fuel economy in the case of the batch type of oven is usually much lower than in the case of the continuous oven, and the labor charges are much higher.

The continuous japanning oven differs from the batch type only in that it is a long heat-insulated box, usually open at both ends, and equipped with conveying means for continuously carrying the material to be treated through the oven. In all plants having a production materially in excess of 100 cars per day the continuous oven is preferable. Continuous ovens are constructed in many varying designs, some typical installations being shown in the accompanying drawings. For treating automobile bodies in cases now becoming relatively numerous in which no wooden parts are built into the metal body, it is usual practice to employ an oven about 140 ft. long, 5 ft. wide and 6 ft. high. The ovens are generally entirely horizontal in this case, but are provided with vestibules which serve to reduce the circulation of cold air from without, thus keeping the temperature within the oven higher and more uniform. In the case of body ovens, two parallel horizontal chains are used for conveyors, the chains sliding in steel channels or angles at a level of about 2 ft. from the floor. The bodies to be japanned are placed on the conveyor with about 4 ft. of space between each. In the case of an oven 140 ft. long, operated at a temperature of 450 deg. fahr., a 45-min.

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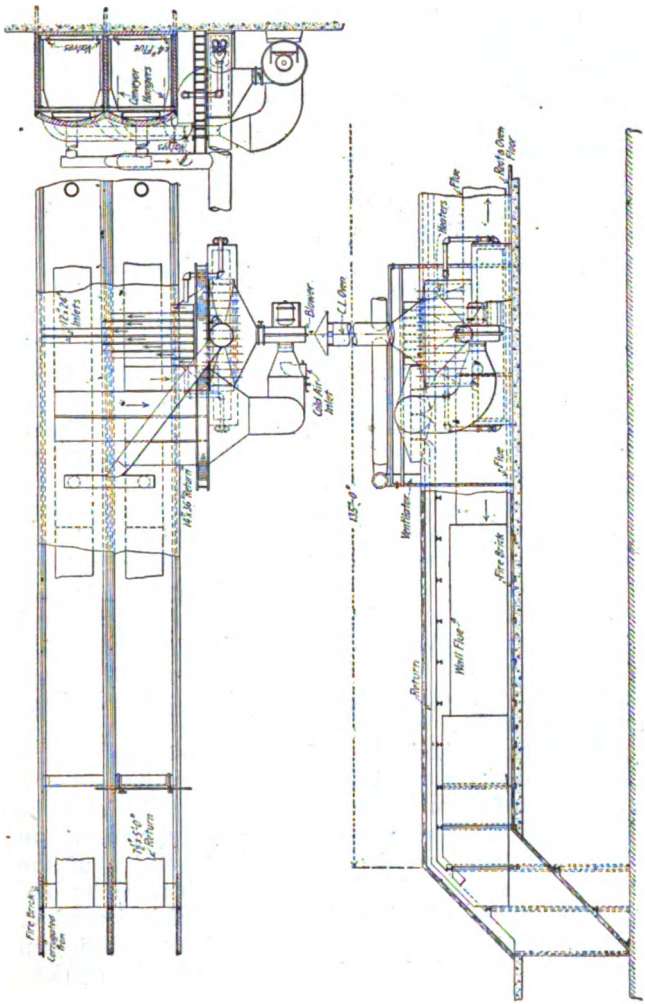

GENERAL ARRANGEMENT OF A 185-FT. OVEN FOR AUTOMOBILE BODIES

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baking period is usually employed, thus allowing a speed of travel for the conveyor of about 3 ft. per min. This rate of travel permits ample time for inspection as the bodies leave the oven, and the application of a second coat of japan before the bodies enter the second oven. Under these conditions, a period of about 10 min. is allowed for inspection and applying the next coat. This, of course, requires a distance of about 30 ft. on the basis of a speed of travel of 3 ft. per min. The above figures are merely given as typical of successful installations now in operation.

The question of ventilation for japanning ovens has already been discussed and it is merely necessary to give some typical figures illustrative of present practice. An oven adapted to the japanning of light automobile bodies, with an hourly production of about 12 bodies, will require an air circulation approximately equal to 1200 cu. ft. of fresh air per min. There are at present a large number of japanning ovens employing natural ventilation to cause the necessary air change. In my opinion this is unfortunate, since the operator cannot control the rate of circulation or the nature of the incoming air.

A second type of japanning oven represents present practice in the treatment of automobile fenders and similar light parts. It will be noted in this case that the entire process of dipping, dripping, baking, etc., is carried out automatically, and that manual labor is required only in placing the pieces to be treated on the conveyor, inspecting them and removing them when completed. There are two typical methods of reducing the leakage of hot air from the oven and the consequent entrance of cold air. Both methods depend upon the lower specific gravity of warm air causing it to rise. In the one case the oven is located on the roof, while the material to be japanned enters at one of the lower floors, passing up an incline before it reaches the hottest portion of the oven. Another method of securing substantially the same result, but modified to deliver the finished product nearer to the point at which it enters, is exemplified in the case of a double-deck fender oven now on the market.

Heating Methods

There are in use today at least three different means of supplying heat to japanning ovens. The oldest and least satisfactory arrangement consists in having a number of gas burners placed beneath the floor level of the

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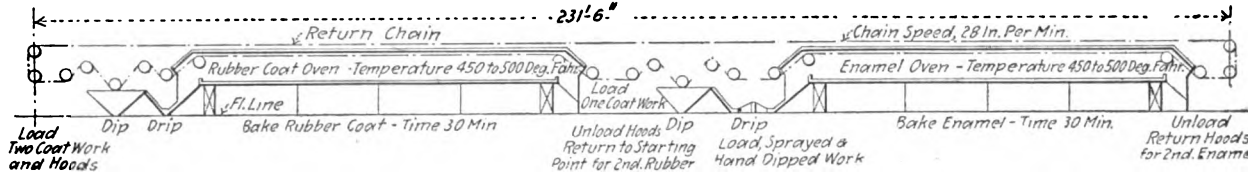
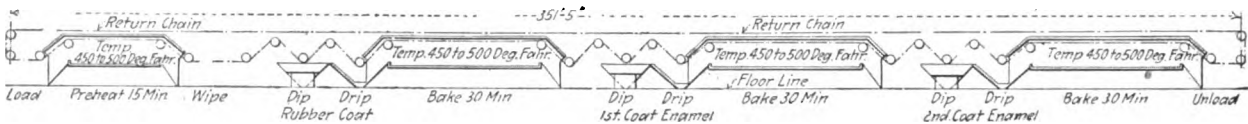

231'-6"
Return Chain
Chain Speed, 28 In. Per Min.
Rubber Coat Oven - Temperature 450 to 500 Deg. Fahr.
Fl. Line
Load One Coat Work
Enamel Oven - Temperature 450 to 500 Deg. Fahr.
Load Two Coat Work and Hooks
Dip
Drip
Bake Rubber Coat - Time 30 Min
Unload Hooks Return to Starting Point for 2nd. Rubber
Dip
Drip
Load, Sprayed & Hand Dipped Work
Bake Enamel - Time 30 Min.
Unload Return Hooks for 2nd. Enamel

GENERAL ARRANGEMENT OF A CONTINUOUS ENAMELING OVEN FOR SMALL PARTS



GENERAL OUTLINE OF A CONTINUOUS ENAMELING OVEN

oven and arranged so that the gaseous products of combustion will pass upward and impart a portion of their heat to the materials to be japanned. The objections to such a system are obvious. The temperatures are not subject to accurate control, the temperature of the ovens is not uniform throughout, the dangers of fire from an open flame are excessive and the products of combustion passing through the oven frequently contain traces of soot and always large amounts of water vapor. As a result of these conditions the quality of the work produced by an oven of this type is not as satisfactory as that of later types, and with the present price of gas the operating costs are high.

The electrically-heated oven has been widely introduced and is in successful use at a large number of plants. Electric heat allows simple and accurate control, permits a relatively uniform temperature throughout the oven and is free from the objections of soot and water vapor inherent in the gas-fired oven. The most serious objection to the electrically-heated oven is the extremely high cost of this form of heat. A consideration of the fact that even large power users cannot as a rule secure a lower rate for japanning equipment than from 1 to 1½ cents per kw.-hr., will make evident the very high costs involved. For example, one large automobile builder producing approximately 1000 cars per day, has a power bill for the japanning ovens alone of about $1,500 per day. For purposes of comparison, it may be stated that the same service secured from japanning ovens heated by the combustion of fuel oil would cost not over $400 per day, giving a yearly saving of over $300,000. It should be noted that while the electrically-heated oven can be most easily controlled and is normally very reliable, yet in this case the manufacturer is dependent upon power service. In case of any interruption of the central station service his ovens are closed, thus stopping all production and possibly causing a material loss of product.

The third and more modern system of applying heat to japanning ovens consists of the so-called air-heated type, in which the ventilating air and radiant heating means are both maintained at the desired temperature by the combustion of oil or gas in a small separate oven composed of refractory materials that serves as a firebox or combustion chamber in which the fuel is burned. Mounted above this is a series of air heaters which are divided into three groups. The first and smallest group

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is employed to supply preheated air for the combustion of the fuel in the heating oven. The second and largest group is used to heat a volume of circulating air which passes through flues arranged longitudinally along the sides of the oven and out, returning through a blower to the heaters. This volume of air serves to transfer the heat which is produced at high temperatures in the combustion oven, to the material to be japanned, where the temperatures are relatively much lower. One large installation of this kind, which may be considered typical, has been designed on the basis of 650 deg. fahr. for the temperature of the air entering the radiating flues and 450 deg. fahr. for the air when leaving the radiating flues. The third set of heaters employed in this system is used to preheat the air used for ventilating purposes, thereby overcoming one of the serious difficulties experienced with the earlier type of electrically-heated oven, namely, the lack of uniform temperature throughout the different portions of the oven.

It will be noted that this latter air-heated type of japanning oven permits of securing all of the advantages of the other types, with the additional advantages of economy, reliability and controllability. It will be apparent that by the use of large radiating flues which cover substantially the entire sidewalls of the oven, and are maintained at temperatures about 200 deg. higher than that of the oven, a large amount of radiant heat is applied to the material to be japanned, with the resultant advantages which have been outlined. On the other hand, the preheating of the circulating air insures that a large amount of warm entering air will be at all times passing through all portions of the oven, thus eliminating the "cold pockets" which are a troublesome feature of the electrically-heated oven. This forced circulation of warm gases also prevents the accumulation of the relatively heavy volatile products formed in the drying of the japan. The fact that the pressure within the japanning oven, by this system, is somewhat greater than the external atmospheric pressure, although only a small fraction of an ounce, overcomes the difficulty which is sometimes acute in the electrically-heated oven resulting from the flowing in of cold air in the horizontal type of oven, owing to the draft induced by the exit of the circulating air.

On the present basis of fuel oil, at approximately 4 cents per gal., it has been found that an oil consumption

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of not over 50 gal. per hr. will entirely supply heat to a continuous body japanning oven 140 ft. long and having an hourly output of at least 12 automobile bodies. This results in an actual fuel saving equal to nearly two-thirds of the cost. In the case of the air-heated oven described above it will be noted that none of the products of combustion enter the oven, and therefore the difficulties inherent in the earlier types of gas-heated ovens are avoided. Obviously no soot or water vapor is carried into the oven from the heating chamber.

Temperature Control

To produce work of a high quality continuously, the absolute control of the temperature throughout the japanning oven is essential. From the foregoing discussion on the properties and characteristics of japan, it will be evident that if the time in which the bodies are submitted to the baking temperature is kept constant, the temperature also must be maintained constant or the japan will be either under-dried or over-baked. Commercial practice has finally reduced successful temperature control to the basis of a pyrometer operated either by a thermocouple or a variable resistance. In either case, the change in an electric current caused by the change in the oven temperature operates a meter which is connected to a relay. The relay is used to close a power circuit controlling an electrically-operated switch, in the case of an electrically-heated oven, or an electrically-operated oil-and-air valve, in the case of the air-heated oven. The quickness of response to slight temperature variations is substantially the same in both cases.

In the case of an oven 75 to 150 ft. long, it is usually good practice to divide the temperature control of the oven into two or more sections, each of which may be controlled individually. It is not uncommon in the case of an oven 135 ft. long to place four thermocouples in the roof along the center line of the oven at approximately equal intervals. In this case, the four sections of the oven would be controlled individually and automatically. It is also common practice to provide manual control in addition to the automatic control, in order that the temperature of the oven as a whole can be varied when necessary. The necessity for such variation has resulted very largely from the use of natural draft, and the consequent variation of oven performance with

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variation is materially less in the case of those ovens in which the ventilating air is preheated and supplied under slight pressure, so that oven conditions and air circulation are independent of weather variations.

It has been previously pointed out that essentially the japanning oven consists of an insulated box provided with heating means and conveyor equipment. There are naturally many different mechanical constructions in use, many of which give satisfactory results. From the standpoint of heat insulation it is good practice to have the walls at least 4½ in. thick, and in case electric power is used for heating, a materially greater thickness is warranted because of the decided economy obtained in operation. It is desirable, in designing the oven, to have a minimum of exposed radiating surface per unit volume of useful oven space. In other words, when possible, two or more ovens should be grouped together, thus reducing radiating losses. In connection with the location of ovens, it may be pertinent to suggest that in many cases they can be placed on the roof, thus economizing floor space.

In constructing a japanning oven it is essential that the walls be air-tight in order that there may be no leakage of gases either into or out of the oven, other than as provided by the ventilating equipment. The oven structure should be as light as possible consistent with mechanical strength. Consideration must be given in the design to the fact that in a length of 100 to 150 ft. the total expansion resulting from a temperature change of about 400 deg. fahr. may be several inches. Particularly in case ventilating and heating flues are introduced and designed to operate at higher temperatures than the remainder of the oven, the factor of thermal expansion must be considered. Much stress has been laid upon the desirability of avoiding all so-called "through metal" in oven construction. Undoubtedly all metal which extends from the inside of the oven to the exterior serves as a source of loss by heat conduction, but it is my opinion that in many cases this factor has been unduly emphasized for trade reasons, and possibly with a sacrifice of other advantages.

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CURRENT DEVELOPMENT OF AUTOMOTIVE INDUSTRIES

By J E Schipper[1]

The paper surveys the economic and engineering aspects of the automotive industry, so that engineers can align themselves with its future development. Better performance and longer life due to improved design and materials distinguish the 1920 car from its predecessors. One of the healthiest signs in the industry is the uniform determination of practically every manufacturer to improve the quality of his product. The designer has been forced to extend himself in getting the highest possible output from the smallest possible units. This trend is very noticeable.

Conditions relating to prices, the return to peacetime production, the potential demand for cars and the present supply, and the probable improvements in cars are then reviewed, the thought then passing to a somewhat detailed discussion of detachable-head engines. Heating devices for intake manifolds are next considered, followed by a rather lengthy rehearsal of the factors involved in connection with wheels and axles and the subject of pneumatic tires for trucks. A discussion of truck-engine development is presented. A résumé of production statistics is given, the prediction of increased production being made unanimously by the executive heads of factories. The labor outlook is then treated. Standardization as an accomplishment of the Society is mentioned, the attractions of a world market are pictured and the possibilities of the motor-truck industry are enumerated.

Now that the two great automobile shows are over, we have a bird's-eye view of the year's developments. It is not only interesting but of the greatest importance to those of us who earn our livelihood from this great industry to take a survey of its economic and engineering aspects, in order that we may align ourselves with its future development.

Better performance and longer life due to improved design and materials distinguish the 1920 car from its

[1]Technical editor, Class Journal Co., Detroit.

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is the uniform determination of practically every manufacturer in the field to improve the quality of his product. The high relative demand is only one reason for the higher prices. Besides this the higher labor and material costs are factors, but even were it not for these considerations, the better materials and workmanship would in themselves be causes of increased price. The realization of the fact that to stay in business it is necessary to build a good car is responsible for the effort of manufacturers to produce the best that is possible in the price-range served. Owners are demanding performance from the low-priced cars to just as great an extent as from the higher-priced products, the greatest differenees being in the finish, upholstery and the size. The demand for acceleration and high-gear performance is greater now than it ever was, and it has forced the designer to extend himself in getting the highest possible output from the smallest possible units. This trend is very noticeable this year.

Prices are not going to come down yet. When the War Industries Board in the late summer of 1918 ordered the industry to go on a 100 per cent war basis by Jan. 1, 1919, it set in motion a chain of events which has had its effect upon every branch of automobile manufacture and sales and left an impression on the industry which will be noted for a long time to come. In the first place, production immediately started to decline, until it had dropped far below demand. Then came the armistice and an immediate scramble on the part of the factories to get back to a peace basis. Naturally, the first thought in the mind of the majority was that we would have the post-war car. The automobile manufacturer, it was thought, had during the war period prepared a design which would be ready for the public as soon as the war ended. It was therefore with a rather expectant attitude that the general public and most of the dealers approached the show in 1919 and awaited announcements during the early part of the year. But, this was not to be, and a moment's thought will readily show why. The engineering brains of the industry which in peace times would be focused on the drafting-board, in getting out new designs of car and truck, were busily engaged in ordnance, quartermaster and aircraft service. New tools were scarce and even if designs had been produced, tooling for production would have been impossible. The result was naturally just what would have been expected. The

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manufacturer, to meet to some extent the demands of the dealers who swarmed into his offices imploring him for cars, had to go back to where he left off and continue the old model with what few minor improvements had been decided upon before the armistice.

It was not easy for many of the manufacturers to get back to the peace-time production. Those who made war products that were closely related to their regular work were in an advantageous position, and naturally were soon grinding out a fairly reasonable production. On the other hand, factories which had taken out all of their own machinery and installed Government machinery in its place were in a bad situation. One company, for instance, had ripped out its entire upholstery department, had installed sewing machines and was busy turning out trousers for the soldiers. It is impossible to switch overnight from trousers to upholstery. Furthermore, the Government was not altogether too rapid about settling financial adjustments, and the outstanding capital was a sore handicap to many a plant that had invested heavily in special machinery and materials to carry on war work. All of this caused a delay in getting started, which not only allowed the pent-up demand to increase, but furnished a real opportunity for the engineering department, which had come back from the war, to concentrate on new designs. The result is that the 1920 cars, which have just made their appearance, and those which will break through the shell during the year of 1920 are the first real post-war products.

It is estimated that today there is a potential demand for 2,000,000 cars. This started to accumulate in 1918. Up through 1917, demand and supply were running a very close race, growing about uniformly, and there was a fairly easy absorption of the 1,800,000 cars produced that year. It was estimated that the production for 1918 would be 2,500,000. Instead of that only about 1,000,000 were produced, because of the war. Production totals for 1919 were 1,587,000. If demand had increased only as fast as normal, the 2,000,000 shortage would be a conservative estimate.

There is every reason to believe that the spring of 1920 will witness the greatest buying activity ever seen in the automobile field, just as this winter the demand for enclosed cars is, and will be, far in excess of the possible production of these vehicles. At present there are between 6,000,000 and 7,000,000 cars and trucks on the

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streets and roads of the country; in five years there should be 15,000,000. The extent to which the truck and passenger car will displace other forms of transportation is governed by only two things; the production of vehicles and the building of good roads.

In 1912 we had 325 manufacturers of passenger cars. Today we have less than 100 who are actually producing. But those who are in business now have seen the error in the ways of many who have failed, simply because the car was built for a price and dumped upon the market with consideration for the life and performance of the car given last place. It is recognized that the first requisite of an automobile manufacturer today is that he build a good automobile, even before he gets a good sales department or an efficient advertising manager, and it is this spirit and knowledge that are responsible for the trend toward improvement. The industry and the product are in a period of change. The consolidation of capital and the vast production required to build a low-priced car is forcing this business into the hands of a very few large producers and here it is likely to remain unless some inventor of tremendous genius can show a way to build a better car for less money. The new cars are automatically forced into a class selling for $1,500 and upward. It is in this field that we shall find the new cars, and there are many of them to come. At present there are probably a dozen new active organizations preparing to put out cars, some of them on a large scale.

Improvements in the cars are taking on definite shape, and it is not difficult to trace the probable trends for the next two years. Probably the most noticeable development will be the great replacement of the touring car by the sedan and other types of enclosed bodies in the higher-priced cars, and a vastly greater percentage of enclosed cars as compared with open in the lower-priced field. One company, for instance, which three years ago had an enclosed-car schedule of about 15 per cent, is now making 60 per cent enclosed cars. Others are following suit. The number of enclosed bodies sold is governed by the production, and this in turn has been materially affected by the labor troubles which are so widespread. In the past few weeks, for instance, the coal strike has greatly cut into the supply of glass, and the result is a curtailment. The upholstery and trimming departments of a number of factories have been affected also, but as fast as these troubles are cured, production will mount and

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the sedan will eventually occupy the place now held by the touring car.

Detachable-Head Engines

Probably the most significant improvement and tendency in engines from the repairman's as well as the manufacturer's standpoint is that of the detachable-head engine. This is notably on the increase and in fact it can be stated that not a single important new engine has been brought out this year which is not of this type. A particularly interesting detail in connection with the detachable head is the practice of putting small lips or lugs on the casting so that the repairman can remove it without damaging the gasket. With the ordinary flush type of top it was necessary to use a cold chisel to start the head after the studs had been removed, and this in every case necessitated the replacement of the head gasket. With the lips or lugs now cast on the head, it is possible to start its removal without damaging the gasket, which permits the use of the same gasket upon replacing the head. The detachable head, of course, provides greater accessibility for cleaning carbon and for inspecting the cylinder bore. It also permits the manufacturer to machine the combustion chambers accurately, thus securing absolutely even compression in all. With the overhead type of valve in connection with the detachable head, the entire valve assembly and rocker-arm units are removable together with the head, making it possible to work on a bench where the light is better and it is easier to use the desired tools.

In connection with the valve-in-head engine, some new ideas have been brought forward this year and incorporated on a great many of the new products. I refer particularly to the use of an open-sided cylinder-casting on the side on which are located the valve-rods. An aluminum cover-plate is put over the open side, which extends down into the crankcase, thus providing a clear opening from the head down to the case, allowing the oil spray to be thrown up to the overhead-valve mechanism and permitting it to operate in an oil mist. The criticism of noise which was generally directed against overhead-valve engines a few years ago, has been distinctly overcome in the new models.

A feature on all of the new engines is that the crankshaft and the crankshaft bearings are being made so heavy that it is probable that there will be fewer cases

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of bearing trouble in these new engines than ever before. It is not unusual for crankshafts to run up well over 2 in. on engines of the size which formerly employed 1¾-in. shafts. Pressure-feed oiling, which supplies the oil in sufficient quantities to cool as well as lubricate the bearings, has rendered these heavy shafts possible; and by their use the periodic vibration has been practically eliminated. On many of the new cars it is possible to remove the oil-pump from the exterior of the crankcase by withdrawing exterior cap-screws. This is a point which will be appreciated in cleaning out the oiling system and in overhauling the pump, particularly by those who have had in some cases to tear the engine down to reach the pump.

Aluminum Pistons

While aluminum pistons are used, they are not giving the trouble which was formerly experienced with them when it was attempted to cast aluminum pistons from exactly the same pattern as was used for an iron piston. It has been realized that the characteristics of the metal must be taken into consideration in manufacturing an aluminum piston, and the result is that the correct clearances have now been discovered and the correct method of stiffening the piston has been utilized to the elimination of trouble. It is of interest to note that where aluminum pistons were formerly used, first for their lightness and second for their heat-dissipating qualities, the situation has now been reversed and all of the aluminum pistons are of heavy section to secure the dissipating qualities, with lightness a secondary consideration. In fact, some of the new iron pistons are practically as light as the aluminum pistons. On the other hand, another company has this year returned to iron castings in place of aluminum for the cylinder blocks. However, these castings have been so carefully designed and are relatively so light that it is estimated that there is only 50 lb. difference per engine, due to the use of the iron cylinders. One engine uses an aluminum cylinder casting with what may be known as the wet-sleeve construction, as the cast-iron sleeve fits directly into the aluminum casting in such a way that the water is between the sleeve and casting and washes directly against the outside of the cast-iron liner. This construction is used in Europe to some extent, but this is the only American factory

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following this practice. Aluminum has been used very extensively by manufacturers generally this year. One new small six-cylinder car has an L-head engine with the detachable head an aluminum casting incorporating the intake manifold. This exposes the lower part of the intake manifold to the heat of the combustion chamber and assists in vaporizing the gasoline.

Heating Devices for Intake Manifolds

The question of hot-spotting intake manifolds has continued to occupy the minds of engineers, but there has been an almost universal drifting toward the practice of arranging the hot-spot so that only the liquid or unvaporized portions of the fuel come in contact with it. In one type of design the inertia of the liquid or unvaporized fuel is made use of. These heavier particles have by their own mass sufficient kinetic energy to carry them across to the hot walls, whereas the vaporized portions pass directly into the intake passage and to the valve ports. On one of the season's newer engines, the heavier portions by their own weight lie along the bottom of the intake passage, which is integral with the aluminum engine head, and these are vaporized by the heat of the combustion chamber. In another, an eight, the intake is exhaust-jacketed, and owing to the fact that the intake bridge is across the V between the engine blocks, there is a surging action of the gases to and fro from one block to the other, this giving the desired impinging effect to assist in vaporization. Another burns a portion of the fuel by means of a spark-plug inserted in the manifold, to heat the ingoing charge. Several other engine types allow the intake gases to pass across between the two central cylinders of the block. A new stock engine which will be used in a great many of the assembled cars, possibly twenty-five at the present writing, incorporates an exhaust-jacketed manifold, the intake being cast integrally with the exhaust and in contact with it to a certain degree to assist vaporization.

Some of the engine details which are particularly noticeable are the trend toward larger valves and ports, the use of die-cast babbitt bearings for the rods and main bearings, chain drive for the timing-gears, and more complete distribution of the oil pressure feed to different parts of the engine. The use of the die-cast bearings makes it necessary in a great many instances to return the rods or main bearings direct to the factory for re-

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placement, unless the repairman is equipped to do his own die-casting on a mandrel. This is not an easy job to handle without special equipment and consequently this new construction will result in handling bearing repairs by replacing the entire assembly, with allowance being made for the part turned in. Iron-backed bearings instead of bronze-backed are claimed to have advantages.

Clutches do not show much change this year as far as construction is concerned. There has, however, been a tendency toward the adoption of the dry-plate type by a great many manufacturers. One three-plate type is used on nearly sixty makes. The number of plates utilized runs all the way from three to seventeen; three, five, eleven and seventeen being the predominating numbers. An attempt has been made by some of the manufacturers to increase the leverage of the clutch pedal to make the car easier to handle, particularly by women, and in this respect there are some notably good designs. Short travel at the clutch for disengagement is, of course, easier with fewer plates.

Unit powerplant construction has remained popular. Only one new car to be made in quantities this year does not use it. The Hotchkiss drive continues to be popular, but recently there has been some talk among engineers of dropping it in an attempt to secure easier spring suspension. Two new cars exhibited at New York for the first time had torque members. One has a tube which encloses the entire drive, and a triangular stay layout from the front end of the torque tube back to the outer extremities of the rear axle. The other has a torque arm and radius-rods.

Wheels and Axles

Semi-floating rear axles are gaining in popularity and there is a tendency toward redesigning the axle for lightness. Some of the newer axles have bearings on both ends of the pinion shaft, which tends toward stiffness and also permits of a single pinion-shaft carrier which can be removed as a unit. All of the newer types of axle have very accessible adjustments for the pinions and ring-gear mesh, from the outside of the axles. The employment of aluminum axle housings can be expected in the near future. Castings have already been introduced which are said to be satisfactory for this part of the chassis. Although this is more expensive than the present construction, it results in a material reduction of un-

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sprung weight, which a great many manufacturers deem of the utmost importance.

The use of aluminum wheels is also among the future possibilities, the new castings shown at the New York and Chicago exhibits having attracted notable interest. It is stated that it will be possible to provide wheels for a 3000-lb. touring car weighing but 19 lb. apiece, which of course would make a material reduction over present types, although no doubt much more expensive.

There has been some lengthening of wheelbase due to a desire to increase body room. On the other hand, some manufacturers have shortened the wheelbase and yet accomplished a great deal in the bodies. The most notable instance of this is, of course, the overhung frame. Frame side members have been deepened almost universally and the transverse members have been more firmly gusseted than ever. In the chassis oiling system there has been an increase in the use of the high-pressure grease-gun type of lubrication, which is used on a great many cars now as stock equipment. The oil-cups have continued to increase at the expense of the ordinary type of grease-cups. One car at the New York show with a centralized system of chassis lubrication excited a great deal of interest, and it may be that some of the features incorporated in this will find their way into other chassis. Some of the new models in the lower-priced class have gone to the transmission-shaft brake. Whether this will be a definite tendency remains to be seen. It certainly results in cleaning up the chassis and freeing it from an extra set of brake-rods, and also provides an efficient brake for emergency use. In all cases where the transmission brake has been installed, it has been for the hand-brake and not the foot-brake. The straight-line type of body predominates this year. There is a tendency toward the abandonment of the bevel edge which became popular two years ago. A sharp angular break at the hood, continued back to the rear end of the body, is noticeable in a great many of the new types, and it might be called the distinguishing line of the 1920 products.

Pneumatic Tires for Trucks

In outlining the engineering trends of truck design, the paramount feature is the tendency toward pneumatic equipment in the capacities above 2-ton. If this development goes forward at the rate predicted by the big tire

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manufacturers and a great many of the truck builders, it will have a radical effect on truck design during the next two years. Pneumatic-tire sizes above 12 in. in diameter have already been developed and it remains to be seen whether the truck manufacturers will use them on the heavier-capacity trucks. If they do, it will mean higher speed and lighter chassis parts and in general a higher pay-load proportion as compared with the weight of the truck. Up to date, the development work along these lines has been done by the tire companies to a greater extent than by the truck companies. During the coming year the experimental departments of the larger truck companies will no doubt go into the matter in even greater detail than the tire manufacturers have during the past year. The establishment of long-distance hauling at high rates of speed on heavy-capacity vehicles has practically compelled the use of the pneumatic tire for this type of service at least, and the limitations of the truck engine and chassis designed for solid-tire work have soon been met when the truck was mounted on pneumatic tires. Changes in the speed range and gear ratios will be only a minor part of the complete overhauling in design which can be expected from this important development.

Looking over the new models brought out during 1919, the fact which impresses one most is the marked effect upon commercial designs made by the Class B military truck. That this truck was a product of the best that the combined efforts of truck engineers were capable is the belief of a great many of the truck manufacturers, if the eagerness with which they have adopted a great many of the features of this truck is any criterion. To give an example of the effect of the military-truck design on commercial practice, it is only necessary to study the gearboxes fitted during the past year. In the Class B military truck a four-speed gearbox was used with an extremely low gear ratio to provide a practically non-stallable vehicle. This same feature has been incorporated on so many of the trucks for 1920 that it has changed the percentage tables so that the average equipment on trucks of 2, 2½, 3½ and 5-ton capacities is a four-speed gearbox for 1920, whereas it was three-speed for 1919.

The economic situation in the field of small-capacity trucks is not as tense as it is in the production of the low-priced passenger-car. A truck manufacturer with a

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smaller production can, in common parlance, "get away" with a fairly small production. This is evident by the fact that there are ninety different models of 1½-ton truck on the market, and seventy-three models of 2-ton. The 1½-ton truck is the most popular type, filling as it does the widest field. However, there is a strong tendency toward an increased number of 2-ton trucks, particularly in territories where it is possible by means of good roads to develop fairly long hauls. The increased use of the pneumatic tire on the 2-ton truck is also promoting the popularity of this model to a considerable extent.

Truck Engine Development

A great many truck engineers believe we are on the eve of important engine developments in the truck field. There is no doubt that these developments will be largely due to the higher speeds demanded of trucks. With the fitting of pneumatic tires to the 2 and 3½-ton models, the average speeds have risen from 12 to 18, and even to 25 m.p.h. in the sparsely-settled districts. This may prove to be too high a speed range for the type of truck engine which has come to be associated with the solid tires. These engines, running at 1200 to 1400 r.p.m., may not be of a sufficient speed to function efficiently in connection with the gear ratio demanded with the pneumatic tires. It is possible that truck engines will peak at nearer 1800 and 2000 r.p.m. if developments in the pneumatic tire are carried forward. It is very probable that on these higher-speed engines the governor equipment will be modified, and on certain types of service not be used. As a matter of fact, the development in this line is controlled very largely by the building of good roads. The future development of the truck can almost be said to depend upon the road situation throughout the country.

At the present time there are about 2,500,000 miles of good roads in the United States, of which less than 300,000 miles are hard-surfaced. This condition will no doubt change rapidly during the next few years on account of the big appropriations made, not only by the States individually, but by the Federal Government for the development of national highway systems.

The total money available for road building throughout the United States is about $2,000,000,000, of which about $400,000,000 is available for the development of the national highway system. This immense amount of money could not be expended in less than three years with present

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labor and material conditions. The fact, however, that referendums on road appropriations are practically always carried shows that there is a marked tendency throughout the country for the development of highways.

Mechanically, there have been very few changes in truck engines during the past year. Manifolds have been redesigned to some extent so that the intake is partially heated by the exhaust to assist in vaporization in cold weather, and also to reduce the length of time required to warm a cold engine. Another important feature is the marked tendency toward the fitting of the electrical equipment on trucks. There are six ½-ton models on the market for 1920; all of these are furnished with electric lighting and two have starters as standard equipment. Of the twelve ¾-ton models, five have electric starting, lighting and ignition. In the 1-ton size, two out of ten are furnished with electric lighting which has been specified as standard equipment, while the other eight models provide it at an extra cost varying from $35 to $125. Of eleven other 1-ton models, which can be had with electric starting and lighting, only one model has it as standard equipment. The others furnish it at extra charge. On the heavier capacities there is an increasing tendency toward fitting full electric equipment. Another development in truck engines, which will follow along the line of developments in the passenger-car type, is the use of temperature control. At present there is only one company fitting a thermostat to its truck, but it is likely that others will follow suit during this year.

In the development of clutches there is not much new to relate. The dry-disk clutch, which gained supremacy in the field during 1919, still carries off the palm for 1920 as most popular. Clutches of this design have gone upward of 75,000 miles without adjustment on passenger cars, and are giving equally as good satisfaction on trucks even in the heavier sizes. Transmission gearsets have not varied in type, except for the addition of the fourth speed. There have been no noticeable tendencies in design in this part of the truck; the gearset is more or less a standard matter.

The final-drive situation shows a gain for the internal gear when considered by models. Considered by production, the status remains about the same as last year, except for a drop in the use of chain-driven vehicles. Or. if considered by models, which is the true way of de-

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terminiŋg popularity, each model can be considered a ballot by the engineering department of the company producing it, the internal-gear drive has grown to 26 per cent, as compared to 19 per cent in 1919. The worm drive has remained about the same, the percentage being 66½ per cent for 1919 and 65 per cent for 1920. The gain of the internal gear has been at the expense of the chain and bevel drives, these having dropped from 8¾ to 5 per cent and from 5 to 3 per cent respectively. There are many, however, who predict that there will be a marked increase in the use of the bevel drive if the pneumatic tires become practically universal on the 2 and 3½-ton sizes.

Production Statistics

As far as truck prices are concerned, there is very little increase over the average price of 1919, considering the labor and material situation. The percentage of increase, as a matter of fact, is 4.3 on all models, and the largest price increase is 12.4 per cent on trucks of 3-tons capacity. The prospect for a reduction in truck prices is not in sight; in fact, it may be that increases in prices will be prevalent during the early part of 1920. It is quite within the realms of possibility that prices will begin to decline toward the end of 1920. Production will increase. The year 1920 will probably be the largest in the history of the industry. The year 1919 has proved to be the largest so far. The production for 1919 was 305,142; for 1918 it was 250,000 and for 1917, 190,000.

In spite of the fact that the industry was practically on a war basis Jan. 1, 1919, making possible only a small production during the first three months of recovery, 1,587,000 cars and 305,000 trucks were made during the year. This is only slightly less than 1917, a normal peace-time year, when 1,741,000 cars and 128,000 trucks were manufactured. Thus the passenger-car business of 1919 can be said to have been practically back to normal and the truck business nearly three times that of the last normal peace-time year. The mere figures of production, however, do not begin to tell the story. In spite of the large output, the supply of cars was far below the demand, and it is conservatively estimated that the year of 1919 has turned over to 1920 an unsupplied demand for 2,000,000 cars. From the motor-truck angle,

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the opening of 1920 saw unfolded the brightest prospects that have ever confronted the business. Turning our attention again to the passenger-car industry, we find that it has become one of the greatest in the world. The output of cars for 1919 was valued, from a wholesale standpoint, at $1,400,000,000, an average of $882 per car. If production had kept pace with demand, the value of cars produced would have been $3,000,000,000, with cash-in-hand buyers, both wholesale and retail, to be found all over the country and in fact all over the world, waiting for the cars of American manufacture.

The year 1920 has two big problems. The first that of production, and the second, of merchandising. The problem of production is governed almost solely by labor. It is the labor condition which holds up our supply of glass, steel or other basic materials, without which the automobile cannot be built. Remove this throttle, and production will jump ahead at an amazing rate. The waiting, ready demand keeps moving ahead so rapidly at present that this factor of production overshadows that of merchandising, and yet the day of the latter is so surely coming that only the most short-sighted manufacturer is not making ready and laying his plans for the day when a well-organized distribution scheme and personnel is required. Although at present subdued under the avalanche of demand, both domestic and foreign, the merchandising fabric which was destroyed by war conditions is rapidly being repaired. Intensive selling methods will return to use, and the country will be again dotted with dealers and sub-dealers who for mere lack of cars were forced to suspend temporarily.

Returning to the production angle, the automobile industry begins to loom as a candidate for first place among the manufacturing industries of the country. Today it is second only to steel and, with the great amount of other products involved and the other industries directly and indirectly affected by automobile manufacture, it stands today as probably the most dominant factor in American life. Certainly the effect of the pent-up demand was felt in the spring of 1919, when cars were at such a premium that options on delivery were selling for big prices. The world is scrambling for cars; therefore, every factory is going to make every possible effort during 1920 to turn out all the cars it can. This situation is bound to cause the creation of new companies. The parts

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manufacturers are so overcrowded with orders that they cannot, in many instances, take on more orders. The result is that the next year will probably witness a marked increase in the manufacture of parts for sale to the trade. This in turn will cause an increase in the assembled-car business and a corresponding augmentation of the volume of the industry.

The prediction of increased production is made unanimously by the executive heads of factories who have made a careful study of this situation. An average of the estimates for the future indicates a production of 2,250,000 cars for 1920, with 200,000 to 300,000 increase per year for five years thereafter. Certain it is that the old bugaboo, commonly termed the saturation point, has ceased to be held up with trembling hands by the pessimistic.

The Labor Outlook

All of this production problem, however, depends upon labor conditions. There are no more progressive organizations in the world than the American automobile manufacturers. Taken collectively, there are no industries in which the workmen are better paid or more fairly dealt with. Like all other industries, that of automobile manufacture has come through a delicate period in 1919, but 1920 is faced with the confidence that the policy of fair dealing uniformly adopted will keep the automobile industry as free as any other from labor trouble. In fact, the general impression is that we are emerging from the period of unrest. Shortage of coal and steel materially affected production during December. In fact, had the coal situation not cleared up when it did, a serious shutdown would have resulted. As it was, many of the factories were compelled to run on part time, and others saved themselves from a complete shutdown by using automobile and other gasoline engines to run their machines.

All of these conditions materially affect the 1920 production situation. Passenger cars have been standardized by the Society of Automotive Engineers to such a degree that an interchange of parts that is not possible in any other field is currently practised. This feature has been the source of envy and amazement to the European manu-

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facturer, who, in his desire to maintain individuality, lost sight of the possibilities of greatly increased national production through standardization. It makes the work of assembling cars for export so much more simple that it is going to be of direct influence in increasing the foreign market for American cars. This foreign demand is so great and the attractions of a world market are so pronounced that all manufacturers have determined to enter the lists for foreign trade. The result of this is that most factories are going to set aside a certain percentage of their production for export regardless of the domestic demand. This is no more than right. It is a patriotic duty, as a matter of fact, to help the United States to establish its foreign trade, and not the least of our exports during the coming years will be automobiles and parts.

The truck industry offers possibilities that bring it, in its particular field, into as great promise as that of the passenger car. During the year 1919 the United States manufactured 305,142 trucks. Production schedules for 1920 call for 430,000 trucks. It is estimated that this will be cut to 370,000 when the final check comes at the end of the year. This drop below the schedule production will be due to lack of materials, and this in turn largely because of direct or indirect labor influence. The fear that the left-over trucks from the Quartermaster and Motor Transport departments would have a material effect on the market has passed, as far as the manufacturer is concerned. A year ago, when we were all making predictions as to the number of trucks to be turned out in 1919, we said that it would amount to not more than 290,000. The prediction was based upon the upset condition of the factories at that time. The quick rally was a surprise to those who are most familiar with the industry, and the actual production exceeded the estimate by 15,000.

The use of the motor truck to replace the freight car for certain classes of work has proved a marked success. The number of companies which are going into both urban and interurban transportation is growing day by day. Trucks are operating on railroad schedules, and indeed have proved to be more dependable on a time basis than the steam roads have ever been. There are truck lines that hold their schedules so closely that they start on the dot, regardless of whether they have a load

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at the time or not. This efficient transportation service will pave the way for future truck business to such an extent that we may look to the time when the national means of transportation in this country will be the truck, in spite of our great railroad mileage.

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FLEXIBILITY IN ORGANIZATION

By John Younger[1]

The only direction in which flexibility of an organization can be considered is that of successful progress. Flexibility uncontrolled is liable to lead to retrogression instead of progression. During the war, every available unit of man-power was called into use, and all specialized intelligence was stretched almost to the breaking point. This was particularly true of the intelligence in the automotive industry. Demands were made in connection with the airplane, tanks, agricultural tractor and submarine chasers, as well as the more stabilized automobile and trucks. The most skilful men naturally gravitated to the most difficult work, in the problems surrounding the airplane and the tank, and, while in general there were not nearly enough men, the scarcity of skill was more noticeable in the older branches of the industry. It was there that the necessity for a flexible organization demonstrated itself.

The first necessity was a rigid base from which progress could be made. This was found in the accumulated data of the industry and in the experience of automotive engineers. These data became the starting points for a flexible organization in the Motor Transport Corps.

Education as a necessity is emphasized, taking account of labor turnover, the advisability of keeping it low, the value of educating an organization, the fallacy of underestimating men because of lack of experience in some particular line, and other matters relating to human inertia. The formation of research bureaus is advocated, the value of this idea having so proved itself during the war that Great Britain, our own important engineering societies and the larger manufacturers are furthering it. The extension of this idea into the problems of employment, industrial relationships and the broad field of sociology is advocated. In conclusion, general remarks are made regarding the present age as one of specialization.

Flexibility is defined by Webster as "the quality of being willing to yield to the influence of others; not invincibly rigid or obstinate; responsive to or readily adjustable to meet the requirements of changing condi-

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tions." It therefore has a limitation equal only to that set by the definition. If, however, we consider the quality of flexibility as illustrated by a rubber cord stretched in both directions, we readily understand that flexible movement has taken place in two opposing directions, and that if a definite progressive movement is to be made, one end of the cord must be anchored to something rigid. In other words, the only direction in which flexibility of an organization can be considered is that of successful progress. Flexibility uncontrolled is liable to lead to retrogression instead of progression.

I am led to take up this subject as one of the lessons of the war. In that period every available unit of man-power was called into use, and all specialized intelligence was stretched almost to the breaking point. This was particularly true of the intelligence in the automotive industry. Demands were made in connection with the airplane, tanks, agricultural tractor and submarine chasers, as well as the more stabilized automobile and trucks. The most skilful men naturally gravitated to the most difficult work, in the problems surrounding the airplane and the tank, and, while in general there were not nearly enough men, the scarcity of skill was more noticeable in the older branches of the industry. It was there that the necessity for a flexible organization demonstrated itself.

The first necessity was a rigid base from which progress could be made. This was found in the accumulated data of the industry and in the experience of our automotive engineers. These data became our standards, our starting points. Incidentally, in this connection I learned the one big truth about standards and standardization. Standards must not be made to express finality, as they so often are. They must, on the contrary, be looked upon as starting points or milestones, measuring progress. I believe that the arguments for and against standardization are based upon the viewpoints expressed, and not so much upon the statements of standards.

We began in the Motor Transport Corps with as much accumulated data as possible, and this information was concentrated in what was called the planning section, although it was really a miniature of the General Staff of the Army. The men composing this group sought out information, analyzed, digested and passed it along in concentrated form to what can be called the opera-

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tive section of the Engineering Division. In other words, we applied in an engineering organization the principle of the machine-shop routing department. This principle can and must be applied in any manufacturing organization, if it wishes to maintain its flexibility and elasticity in these days. The value of a planning department in a machine shop is obvious. Even a small railroad must have its planning or dispatch-board system to insure schedule running. Under present-day conditions, the same idea must be carried higher and higher up, to ensure permanent results.

Education a Necessity

We are fully alive to the meaning of labor turnover and to the advisability of keeping it low, to conserve the sum total of our existing experience. We are just now awakening to a full realization of the value of increasing the store of knowledge in this connection by the education of our men. It is only a step further to consider the education of our organization. An organization is like a large tank, at first partially filled and being drained somewhat by its percentage loss of labor, but being at the same time refilled by the influx of new labor, with resultant slight changes in level. The tank can be filled only by adding something new; the level can be made flexible in an upward direction by the addition of what?

From the human side this has an interesting angle. It might be expressed mathematically by stating that the summation of experience gained or lost is nil when a man's experience is transferred from one organization to another exactly similar; whereas, if his experience is transferred from one industry to a totally different industry, this will in all probability contribute to flexibility in the direction of progress. I am asking you to be flexible in your thoughts, and not hide-bound by convention and what has gone before.

Another of my lessons from the war is that I will, in the future, rarely turn down a man for lack of experience in some particular line. I feel that, in the majority of work, the ability of any man depends not entirely upon his previous experience. It depends also upon his ability to pick up work, to apply certain fundamental principles, to study the work and bring

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a fresh viewpoint to bear upon it, so that actual progress will have been made at last.

Washington authorities were criticised severely during the war for placing men in so-called impossible situations. Unfortunately, there were many cases of round pegs in square holes, but there were just as many cases, if not more, of men who did not know from past experience that some particular thing was practically impossible, and therefore went ahead to accomplish it. I can cite one case of a man who had been for many years a professor of law at a Middle West university, being put in charge of important engineering work. He was deliberately selected for this work because of his character, training and ability to handle specific details in a way whereby a minimum of time was consumed in getting action. His new viewpoint and insistence upon completion of detail insured accuracy and time saving in handling the long distance work that had to be done. I was once told that the value of education lies in the fact that it enables a man to pick up an idea more quickly than the boss can find out how little he knows about it.

I believe we are on the eve of as great a labor shortage as we have ever experienced, a labor shortage which is still further emphasized by a housing shortage and in which not only will there be insufficient skilled labor available but also insufficient skilled intelligence. New viewpoints must be brought to bear upon the problems confronting us. Our minds must become more flexible; they must not remain quiescent, but expand under changing conditions.

Let me indicate some of the more delicate points of human inertia. It is difficult to know what to do with the old, rooted notions in a business; the practice of making old men saints is pursued at the expense of the new, young blood pushing its way upward, finding that this type of organization is too inflexible, too rigid to accommodate it. Youth eventually has its way, but often at an expense that is frightful. Is it possible to so proceed as to overcome our human inertia and become flexible enough to assimilate new ideas and incorporate them into constant progress? The formation of research bureaus, even if a bureau consist of but one man engaged part time in other work, will help tremendously in keeping in touch with the world's progress. The value of this idea has so

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proved itself during the war that Great Britain has appropriated millions of dollars to further new ideas. In our own country the more important engineering societies have united for the purpose of furthering research. The larger manufacturers, appreciating the success of the General Electric Co. in this direction, are following its example. Thus the search for knowledge is now in progress. Nor is research confined exclusively to matters of science. The problems of employment, industrial relationships and the broad field of sociology are now under the microscope and rapidly being developed into science.

The Present, an Age of Specialization

The underlying thought in this paper is that, more than ever before, this is a period of intense specialization, with everything tending to fit us, like bricks, into a narrow standardized world. The skilful architect may take these bricks and build with them edifices that express his individuality, but for the great mass the unit expresses the ultimate, and the ideal there is expressed by maximum and minimum tolerances imposed by custom. I often wonder why we take such pains to educate our children in the mass. They not only learn the fundamentals but also all kinds of what we call "fancy stuff." We send them through the high school and further instill into them all kinds of mathematics, science, biology, psychology and the like. Then, still in the mass, they are turned out into a cold world where some manufacturer employs them to turn out some highly specialized machine part, after a few weeks' intensive shop course. Whether it be in machining automobile parts or in selling ribbons over a counter, specialization rules.

I wonder, however, if we cannot make work more flexible by what might be termed a ruse. For example, labor leaders are calling for a seven-hour day; the eight-hour day is already granted. Yet in Detroit in a plant where the men work the actual net eight-hour day, I am told that large numbers of them go to another plant and work another eight hours. In effect, these men have realized that the problem of the shorter working day is not so serious as the problem of their idle or leisure time. Is there not food for thought in the problem of changing the nature of work, to prevent fatigue and dullness, and fill the present leisure or idle period with pro-

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ductive work? Many have worked long past the time-clock hour at something which interested them greatly. There can be intense pleasure in keeping strenuously at some task that is actually a hobby. The thought is to make our jobs and the jobs around us interesting by encouraging the human aspect of them so that we shall see more than the specialized function.

Flexibility is tremendously important. In an organization it expresses such breadth that I have only been able to touch upon the more obvious points. The last 100 years have witnessed tremendous progress in mechanical science. I feel that we are on the eve of a century of years that will be crowded with a similarly human and sociological progress.

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CLEVELAND SECTION PAPER

PLYWOOD AND ITS USES IN AUTOMOBILE CONSTRUCTION

By Armin Elmendorf[1]

For many years plywood has been used for such automobile parts as roofs and dash and instrument-boards, but it was not until the closing of the European war that the extent to which this material was used in automobile construction greatly increased. The sudden requirement of airplanes created a large demand for plywood which would withstand the severest weather conditions. Glues were perfected that enabled plywood to withstand 8 hr. of boiling or 10 days of soaking in water without separation of the plies. Plywood as an engineering material is discussed. It is then compared in considerable detail with ordinary boards and also with metals and pulp boards, statistics and illustrations being given. The molding of plywood is considered with especial reference to employing plywood for surfaces having compound curvatures, and the limiting factors in the use of plywood for this purpose are mentioned.

For many years plywood has been used for such automobile parts as roofs and dash and instrument-boards, but it was not until the closing of the European war that the extent to which this material was used in automobile construction greatly increased. The explanation of this comparatively sudden demand lies in the improvements in the method of manufacture resulting from the requirements for war material. Prior to the European war practically the entire output of plywood used in automobile construction was glued with common non-water-resistant hide or vegetable glues. On account of the ever-present danger of the separation of the plies glued with these glues when exposed to rain, its extensive use in automobile construction was never realized.

The sudden requirement of airplanes during the war created a large demand for plywood which would withstand the severest weather conditions. Glues were per-

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fected that enabled the Government to draw up specifications requiring that the plywood withstand 8 hr. of boiling or 10 days of soaking in water without separation of the plies. With the perfection of its water-resistant qualities the remaining highly desirable properties of plywood as a structural material for airplanes were made available. In the construction of aircraft strength per unit of weight was the most important factor. In this respect plywood compared favorably with all other structural materials, including high-grade steels. Large quantities were required, particularly thin flat sheets of large area for fuselage construction. Fuselage material must also show a minimum distortion or warping with changes in atmospheric conditions. It must possess high resistance to splitting, must not splinter, must be stiff, absorb rather than impart vibration, and it is necessary that it be moldable. Each of these requirements was fulfilled to a satisfactory degree by plywood.

It so happens that the properties of a material for many parts of an automobile must fulfill exactly the same requirements demanded for airplanes. In order that the power consumption of the car may be kept at a minimum, the weight must be reduced. Materials used should therefore yield maximum strength per unit of weight. They must lend themselves to a good finish and be workable with conventional mechanics' tools. Plywood also fulfills each of these requirements.

Plywood as an Engineering Material

Much of the antagonism that existed in former years to plywood as a structural material can be attributed to the name commonly applied. The term "veneer" was quite generally used irrespective of the number of plies or of the details in the construction. This word carried with it an impression of concealment as if thin sheets of wood of a fine quality were glued over a base of poor material, with the result that the defects in the latter were hidden. Frequent peeling of the face plies also contributed to a general disfavor of this material. In the terminology now being adopted by the industry, the word veneer refers to the individual sheets of thin wood, while plywood is used for the assembled glued-up stock. For automobile parts grain or appearance is usually a secondary consideration, the mechanical properties being of much greater importance. It is for this reason that

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plywood is now frequently spoken of as an engineering material. Like steel or concrete it has certain definite strength properties which, if they are known, can be used in engineering design. With the exception of its use in instrument-boards, plywood is an engineering material in automobile construction. Similar to the plywood which was used in building airplanes, that which is now demanded by the automobile industry may be soaked or boiled in water for many hours without separation of the plies.

With the disappearance of the objections to plywood resulting from the perfection of this material during the war and the knowledge that it can be molded to conform to fuselage sides, the demand for plywood roofs rose. Several large automobile companies now favor this material to the exclusion of all others for the roofs of their closed cars. It is also being extensively used for cab roofs. Three-ply wood of a total thickness of about 5/16 in. is in common use. Panels for roofs have a core or center ply that is usually between two and three times the thickness of the face plies.

In addition to its employment for roofs plywood is used for the following automobile parts:

Dash-boards
Instrument-boards
Door linings
Window frames

Plywood is not applied as yet very extensively to the construction of automobile bodies and disk wheels. The difficulty that must be overcome before plywood can be very widely used for automobile bodies lies in the fact that it cannot be bent in severe double curvature. It cannot be molded to the form of most standard bodies, although with the present trend in design requiring less severe upset of the grain its use in body construction promises to be extended materially.

The weight of the conventional plywood disk wheel has militated against its extensive use for wheels, but by proper design the weight can be materially reduced so that the advantage of great strength per unit of weight can also be realized in wheels.

Plywood Compared with Ordinary Boards

Wood, as is well known, is a non-homogeneous material, that is, its strength properties are different in different

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directions. Parallel to the grain the tensile or pulling strength of a board may be as high as 20,000 lb. per sq. in., while at right angle or across the grain the tensile strength may be only 1000 lb., that is, in the former direction the tensile strength may be twenty times as high as in the latter direction. Practically the same ratio exists for the stiffness or modulus of elasticity in these two directions; that parallel to the grain may be 2,000,000 lb. per sq. in., while at right angles to the grain it may be only 100,000 lb.

In all standard plywood constructions the grain of one-ply crosses that of the adjacent plies at right angle. With this distribution of the wood fibers a very marked increase in the strength across the face grain of a board is obtained. By a proper selection of the thickness of the center ply the strength across the grain of the face of three-ply wood is readily made equal to that parallel to the face grain. To obtain equal tensile strengths the thickness of the core of three-ply wood is made equal to one-half the total thickness of the panel. For equal bending strength the core thickness should be about two-thirds of the total thickness.

The results of extensive tests made by the United States Forest Service at the Forest Products Laboratory, Madison, Wis., on the mechanical properties of plywood show that the well-known relation between strength and weight for ordinary wood holds for plywood, that is, the strength in bending or in tension increases rapidly with increase in the weight. The material tested was three-ply wood in which all plies of a given panel were of the same thickness and of the same species, the grain of the successive plies running at right angles. In most cases eight thicknesses of plywood ranging from 1/10 to 3/16 in. were tested. Since a marked variation in the strength of the wood was shown, further tests on additional material would be expected, according to the laboratory officials, to modify the values appreciably in some cases. It must also be remembered that the strength is greatly affected by the moisture content, increasing with reduction in moisture content.

On account of the great influence of the moisture content of wood on its properties, the factors which influence the moisture content should be understood. It is, for example, not always necessary to submerge wood in water to increase its moisture, nor will mere exposure to high temperatures necessarily reduce the moisture con-

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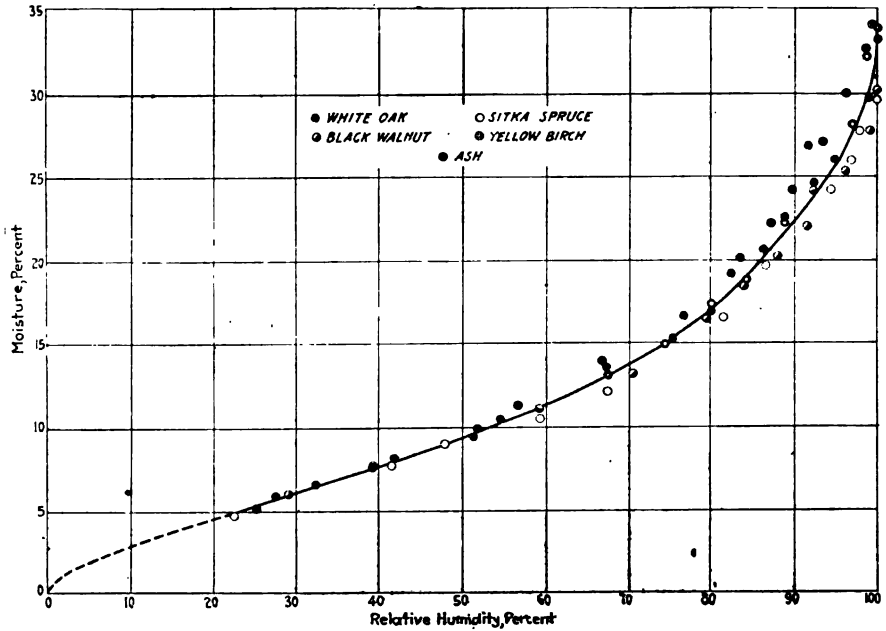

FIG. 1—RELATION BETWEEN RELATIVE HUMIDITY AND PERCENTAGE OF MOISTURE IN WOOD

tent. By exposing wood to relatively high atmospheric humidity its moisture content can be increased, while exposure to low humidities such as in an arid country may greatly lower the moisture content. It is a common observation that the moisture content of the wood in a room kept at 70 deg. fahr. in winter is much lower than that of the same piece of wood in summer when it is exposed to the free circulation of air at the same temperature. The relation between the relative atmospheric humidity and the percentage of moisture contained by wood is quite definite and is practically the same for many species. This relation is shown in the curve of Fig. 1.

The importance of a knowledge of the factors affecting the moisture content of the wood lies in the fact that wood will shrink or expand with any change in the moisture content. Such shrinkage takes place across the grain and is greater for boards cut tangentially from a log than for quarter-sawed boards. The shrinkage with the reduction in moisture content in a direction parallel to the grain is negligible. On account of the great stiffness of wood parallel to the fibers and its low shrinkage in this direction, the shrinkage of plywood resulting from a reduction in moisture content is very low. It is in fact only about as great as the shrinkage parallel to the grain of any ordinary wood. Where a board may be reduced in width by 0.2 in. the corresponding reduction in width of plywood will only be about 0.01 in. It is this marked difference in shrinkage between plywood and ordinary wood that makes it a superior material of construction for many purposes. Least possible shrinkage is desirable in automobile panels because an automobile may be exposed to extremes in atmospheric humidity and consequently the moisture content of the wood or plywood will undergo appreciable changes. Shrinkage may either cause checking of the panel which would mar the finish or it may cause loose joints, thereby introducing irritating noises in driving or even materially reducing the strength of the joint.

In connection with the shrinkage of wood or plywood it should be borne in mind that no paint, varnish or enamel, irrespective of its advertised waterproof qualities, will prevent changes in moisture content of the wood it protects if the exposure to extreme humidities extends over a long period of time. Tests have shown that only

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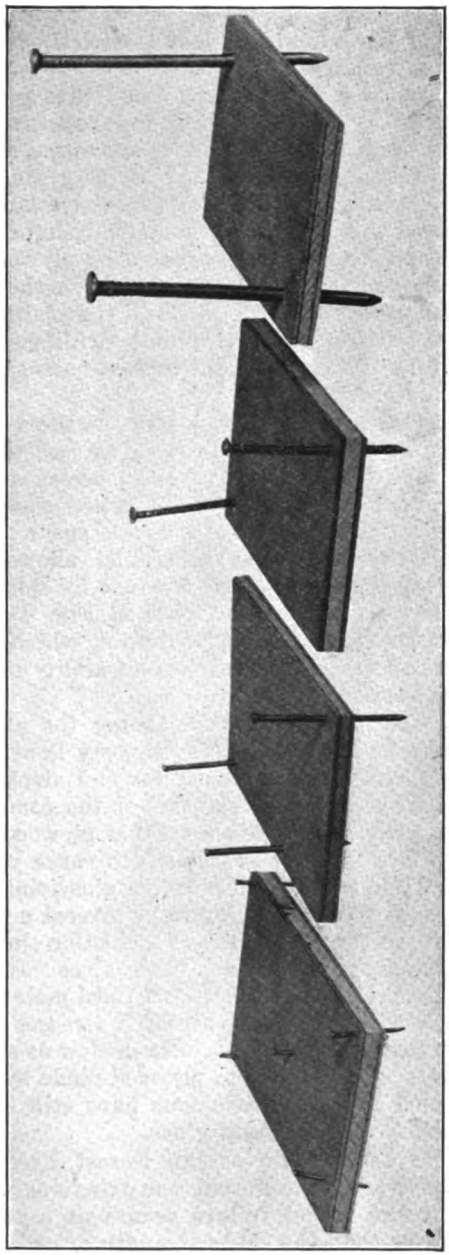

FIG. 2—EXAMPLES OF RESISTANCE TO SPLITTING OF PLYWOOD

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a metallic coating like aluminum leaf is strictly impervious to moisture penetration.

One of the properties of ordinary wood that greatly limits is use for many purposes is its low resistance to forces tending to split the board. This is, of course, due to the relatively low strength of wood across the grain. By laminating and crossing the grain of successive laminations as in plywood this property is materially improved The great resistance to spliting possessed by plywood is graphically illustrated in Fig. 2. The nails in the corners of the small panels were driven into the plain surface of the wood without any preliminary drilling. The sections are 5/16 in. thick. Even the largest nails caused no splitting of the plywood.

The machine shown in Fig. 3 was built at the Forest Products Laboratory to determine the relative resistances to splitting of plywood made of various species, thicknesses and combinations of plies. A test-specimen is shown suspended at the tip of the tool-steel spear. The height to which this spear is raised and allowed to fall is progressively increased until fracture by splitting takes place. The test-specimens shown in Fig. 4 were ruptured in this way. The height of drop at which failure takes place is recorded as a measure of ability of the specimen to resist splitting.

Questions are frequently asked regarding the ability of plywood to resist vibration. This property is of considerable importance in both automobiles and airplanes. Tests made at the research laboratories of the company with which I am associated have shown that plywood can be subjected to vibrations severe enough to cause weakening of the wood and yet no failure in the glue joint will take place. Specimens were subjected to several million repetitions of stress until an actual reduction in the strength of the wood seemed to have taken place. It will be remembered that wood, like other structural materials, particularly steel, will fail under repeated stresses that are much below those which cause failure in slow or static loading. The tests were limited to plywood made by the company mentioned and the conclusions have still to be verified for various water-resistant glues.

Extensive shear tests made at the Forest Products Laboratory on plywood of different constructions have shown that while the initial failure occurs at a stress only slightly greater than the shear strength of ordinary wood, final or complete failure in shear is difficult to

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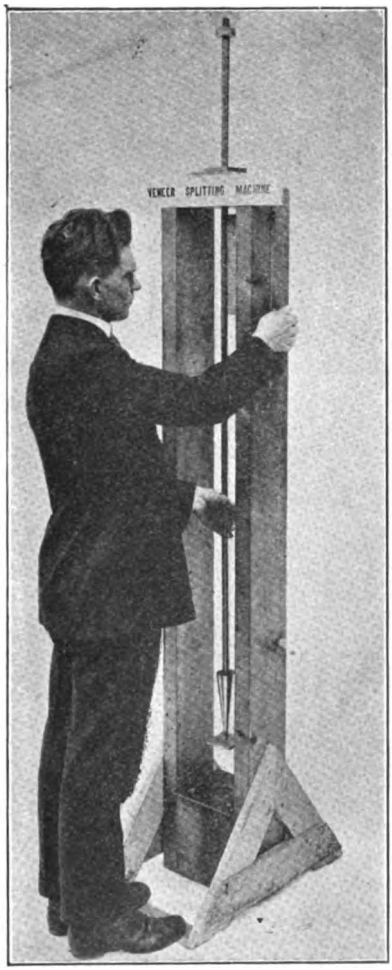

FIG. 3—SPLITTING-RESISTANCE TEST MACHINE

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obtain on account of the tendency of the fibers to hold on in tension. The failure of ordinary wood in shear is sudden and complete, while that of plywood is progressive and prolonged. This property is somewhat analogous to the characteristic of steel described as toughness. A brittle metal will snap while a ductile or tough metal will yield and yet on account of the stretching imparted to it show no failure. Its ductility makes it a superior steel for many purposes. Plywood which is much tougher in shear than ordinary wood is likewise superior to wood in this respect.

Plywood Compared with Metals and Pulp Boards

In comparing the tensile strength of plywood with other materials used for automobiles such as pulp board, aluminum and steel, red gum was selected as a species because it is very extensively used in automobile construction and is of medium density and strength. The strength values given for this material in Table 1 were

TABLE 1—STRENGTH OF AUTOMOBILE MATERIALS

	Specific Gravity	Tensile Strength, lb. per sq. in.			Tensile Strength per Unit of Weight, lb. per sq. in.
		Parallel to Grain	Perpendicular to Grain	Average	
Three-ply wood	0.59	7,850	4,930	6,390	10,800
Pulp board	0.64	1,946	902	1,424	2,230
Rolled aluminum	2.70	.....	.....	19,450	7,200
Mild steel	7.85	.....	.....	60,000	7,650

taken from figures obtained in the tests made by the Forest Products Laboratory mentioned on page 866. The specific gravity given in the table is for over-dry weight. A moisture content of 9 per cent was assumed, which brings the specific gravity up to 0.59. It will be seen that the strength per unit of weight of the plywood is superior to that of the pulp board, aluminum or steel.

In addition to strength, an automobile material, especially if it is exposed in a large surface, must resist impact. If the surface is struck, it should show a minimum tendency toward receiving a permanent impression. Tests were made at our laboratories to compare the resistance to impact of steel and aluminum sheets of the usual thickness used in automobile bodies with three-ply

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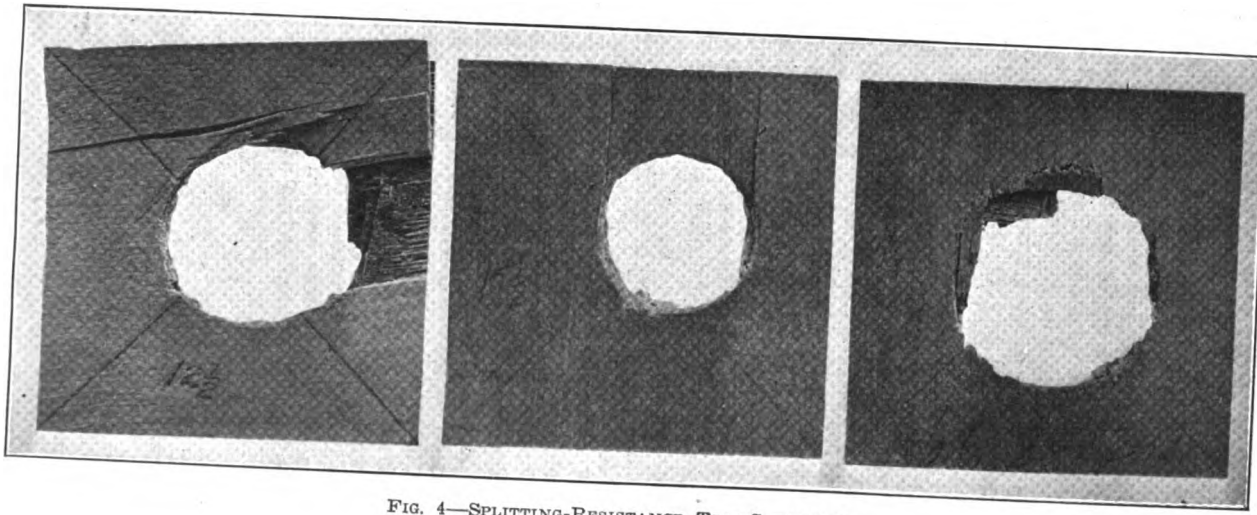

FIG. 4—SPLITTING-RESISTANCE TEST-SPECIMENS

wood of about the same weight. The device illustrated in Fig. 5 was designed for this purpose. A panel was placed upon the surface of a frame 10½ in. square on the inside and a plunger weighing about 12½ lb. was allowed to drop from increasing heights upon the surface of this panel. The results of such impact blows upon panels of steel, aluminum, and three-ply red gum are shown in Fig. 6. It is apparent that the permanent set in the metal panels is very large, while with the exception of a slight dent in the outer surface and minute fractures of the fibers on the inner surface, no permanent deformation was caused in the plywood panel. The results of the test are given in Table 2. It will be seen that the energy imparted to the plywood panels was many times as great as that to the metal sheets. Whereas only one blow was necessary to produce a large dent in the metal sheets, the plywood was subjected to several drops of equal height and even then suffered no serious set or fracture. Under these severe conditions the plywood showed no further injury than slight surface depressions.

The results of slow static loading upon panels of plywood, steel, and aluminum of the same size are shown in Fig. 7. It will be seen that the load at which a material yielded or suffered a permanent set was very much higher for the plywood in both cases. The plywood was also stiffer as indicated by the slope of the curve.

Many erroneous ideas are current pertaining to the construction of plywood, which frequently result in creating an unfavorable impression of plywood as a material of construction. One airplane manufacturer, for example, was under the impression that to gain equal strength in the two directions parallel and perpendicular to the face grain, it was best to use four plies each of the same thickness running two in one direction and two at right angles to it. Experience has shown, and an

TABLE 2—IMPACT TESTS ON AUTOMOBILE MATERIALS

Material	Weight, lb. per sq. ft.	Energy of Blows, ft.-lb.
Aluminum	0.91	16
Steel	1.21	16
Three-ply Haskelite	0.91	78
Five-ply Haskelite	1.16	151

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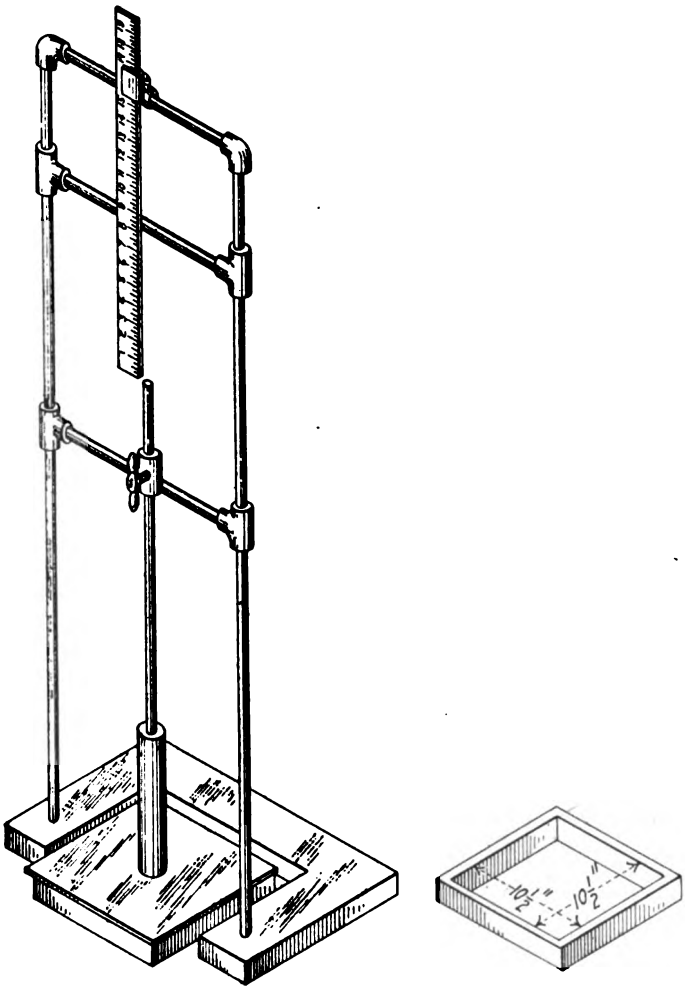

FIG. 5—IMPACT-TEST MACHINE

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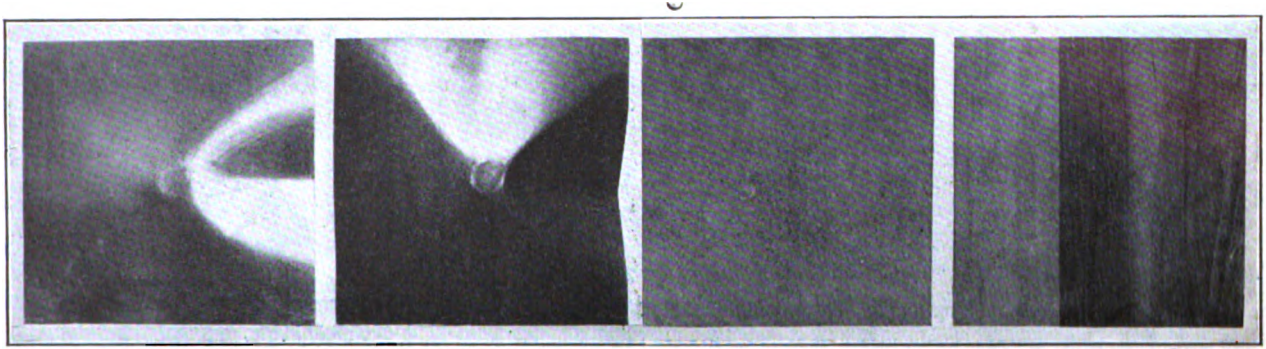

FIG. 6—PANELS OF STEEL, ALUMINUM AND THREE-PLY RED GUM AFTER BEING SUBJECTED TO AN IMPACT TEST

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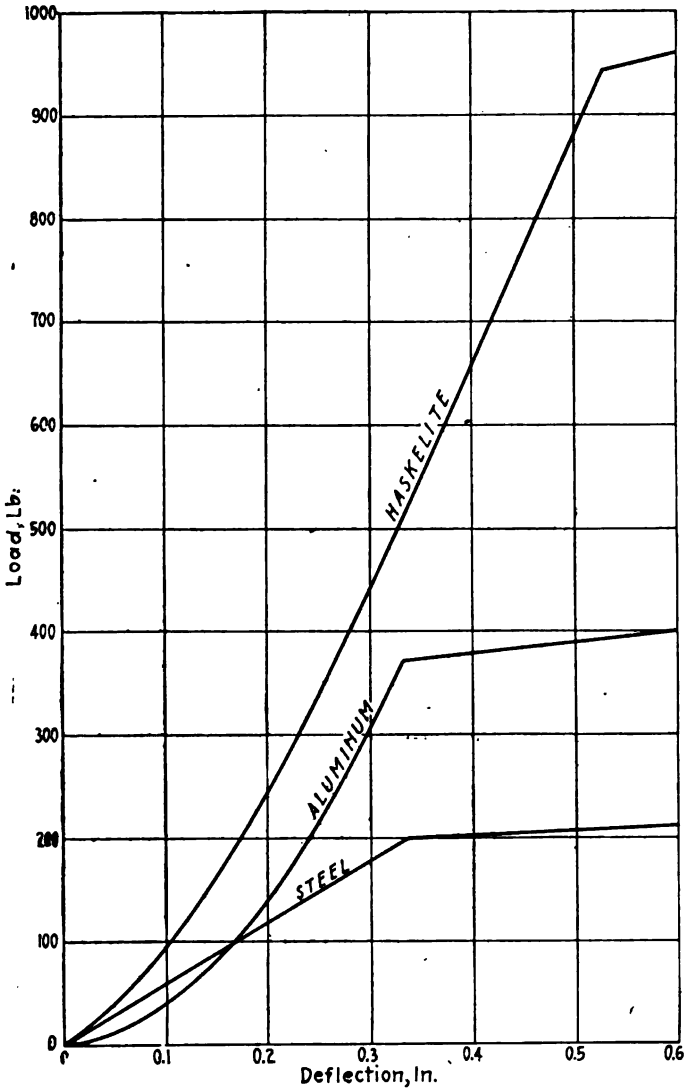

FIG. 7—RESULTS OF IMPACT TEST

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analysis of the stresses introduced bears out, that such a construction of plywood must introduce considerable warping when undergoing moisture changes. The following rule may be adopted to govern the proper construction of plywood so as to minimize all tendency to warp:

> A panel must be made of an odd number of plies and for every ply on one side of the center there must be a corresponding ply on the opposite side at the same distance from the center, of the same thickness, and of the same species or one of about the same density, and having its grain running parallel to that of the first ply. The grain of successive plies should always cross at approximately 90 deg.

Even small deviations of this rule may cause warping in the case of large thin panels.

In making a selection of species it is usually only necessary to examine the density of the species to obtain information in regard to its properties. Hardness, strength, and stiffness are increased with increase in density.

Molding Plywood

The remarkable degree to which three-ply wood can be bent is illustrated in Fig. 8. The strips shown were originally flat. They were placed in boiling water for several hours until the wood fibers were thoroughly softened, then bent over a form and clamped in position until they were dry. Upon removing the clamp it was found that the specimen had assumed and retained the curvature of the form. The specimens were 5/16 in. thick and were bent with the face grain extending around the bend. Bending in simple curvature, as shown in the specimens of this figure, is a comparatively simple procedure.

It is when an attempt is made to bend plywood in compound curvature that great difficulty is experienced. In cases of this kind the wood must be upset. The meaning of this term is best understood by examination of the changes that take place in bending a wood felloe for a wagon wheel. The wood strip intended for this purpose is first softened by steaming and then bent around a form. Careful measurements have shown that the wood fibers on the circumference or outside circle suffer no elongation and that the change in the dimension all takes place due to a shortening of the other fibers. The magnitude of the shortening or upset of the wood

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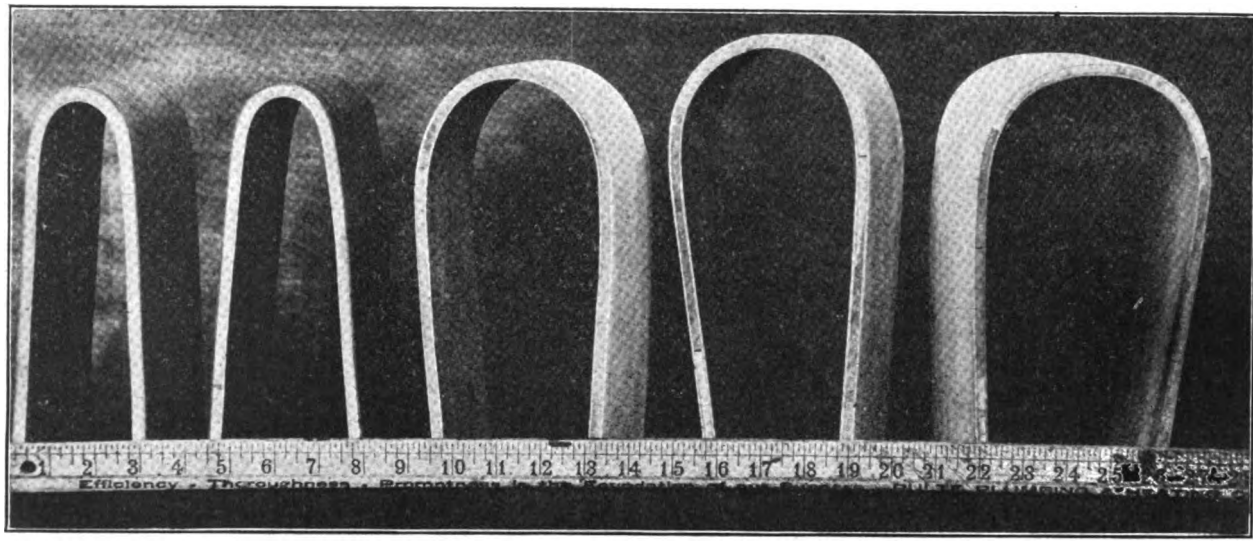

FIG. 8—BENT PLYWOOD

fibers on the inner circumference is given by the difference in the length of this circumference and the outer circumference. This difference expressed in percentage of the outer circumference or original length is termed "per cent upset." It is, of course, evident that even in simple curvature of plywood the fibers on the inside of the bend are upset to a slight degree.

Only in the case of compound curvature, however, must any appreciable upset be given to the material. This will be understood by referring to the diagram in Fig. 9. It will be assumed that a flat circular panel is available having a diameter equal to the arc *adb*. It will also be assumed that the panel is made of a material that is plastic in the sense that it can be upset but cannot be stretched. To make it conform to the spherical surface, its circumference will have to be shortened by a magnitude equal to the difference in the circumference of the two circles whose diameters are the chord *acb* and the arc *adb*. When this difference is expressed in percentage of the original length, it will be seen that for the particular spherical surface of Fig. 9, the fibers along the edge will suffer an upset of 1.5 per cent. A square section 50 in. on edge will be cut out of this spherical surface. The section illustrated conforms to the requirements of a typical motor-truck cab roof. The fibers near the corners are consequently upset 1.5 per cent. The magnitude of the upset at other points can be computed in a similar manner. The computation of upset for roofs of closed passenger cars is more difficult and complicated.

The advantage accruing from bending plywood to double curvature is well illustrated in Fig. 10 which shows in elevation a typical sedan roof made of plywood. Such a roof has supported the weight of five men without suffering any injury. To bend plywood to conform to the curvatures required in automobile roofs, it is necessary first to soften the fibers by wetting or steaming and then to press the flat three-ply panel in suitable dies. Means must be provided for drying the wood because it is only when the fibers are dried in the dies that the upset remains permanently.

Plywood can be fastened to the roof frame in various ways. Typical constructions are shown in Fig. 11. Of these the method illustrated at the left is probably the most common. Some manufacturers prefer to cover the

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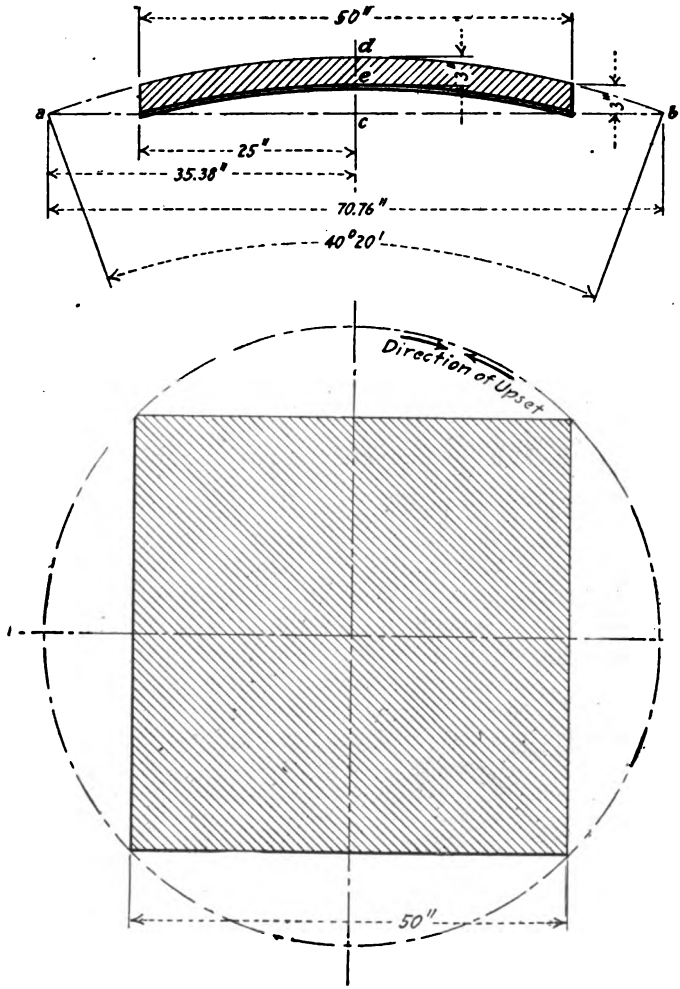

FIG. 9—COMPOUND-CURVATURE DIAGRAM

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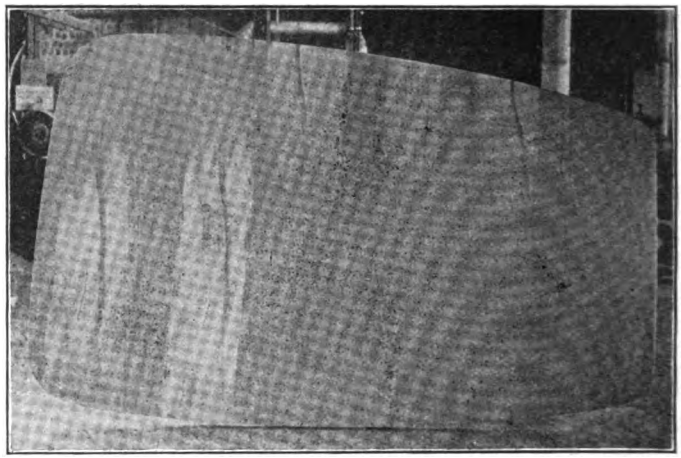

FIG. 10—TYPICAL SEDAN ROOF MADE OF PLYWOOD

joint with cloth to eliminate any possible showing of the joint.

The molding of plywood to compound curvature lends itself to many industrial applications. The magnitude of the upsetting that can be attained is, however, limited.

Such curvatures as those in the cowling of an automobile cannot be made of plywood. Extreme warped surfaces must continue to be made of steel or aluminum.

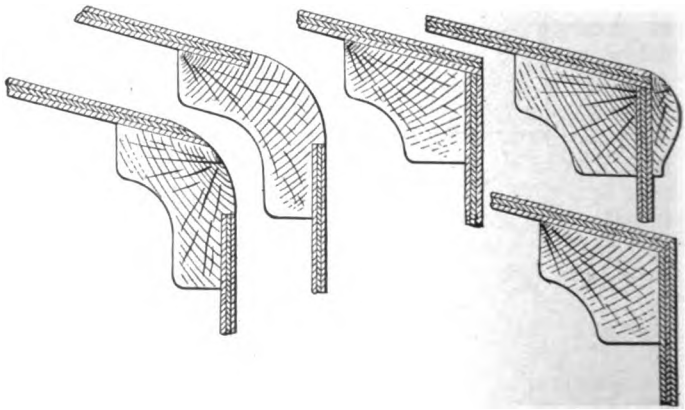

FIG. 11—METHODS OF FASTENING PLYWOOD TO ROOF FRAMES

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In the present trend in design many of the compound curvatures in both body and roof can, however, be made of plywood.

THE DISCUSSION

LAWRENCE OTTINGER: — Mr. Elmendorf correctly points out the limitations of curvature in molding plywood, but ends his paper with the statement that the molding of plywood to compound curvatures is limited and that "such curvatures as those in the cowling of an automobile cannot be made of plywood." This is correct, but it applies only to the molding of plywood in its finished form; after it has been glued, put under pressure, dried in flat sheets and thereafter steamed or boiled before being re-formed. He is not correct, however, in stating that such curvatures cannot be made of plywood if the plywood is formed while the glue lines are still wet. Several body builders are making cowls of plywood, but they apply the glue to the veneers and immediately place them under pressure, the slippage on the glue lines permitting far greater curvature, with practically no limitations. It is possible to mold a complete hemisphere in this way. A thin sheet of veneer can be bent into almost any shape. If the molding is done while the glue lines are still wet, the "upset," or compression, applies to the inner surface of each sheet of veneer. But in rebending plywood that has been completed, the stresses are much the same as would occur in a piece of lumber of the same thickness, because the plies cannot move in relation to each other. This matter is important because body builders are much more likely to make their own plywood than to buy manufactured plywood, for several reasons. One of these is that the same mold which would be used in molding a piece of plywood can also be used to manufacture plywood, provided a cold waterproof glue is used.

ARMIN ELMENDORF:—The statements referred to relate entirely to the molding of plywood that has first been glued into the form of a flat sheet and to the manufacture of cowling by this method. There are, no doubt, certain automobiles in which the cowling is made of plywood, and it was for this reason that my statement was qualified to "extreme warped surfaces must continue to be made of steel or aluminum." The cowling of most automobiles has rather severe compound curvatures. I am aware that "slippage on the glue lines permits far

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greater curvature." I have made tests of this method of molding and, in spite of various ways of conditioning the veneer prior to gluing, found that the veneer would check or split in the faces. To avoid this, I found it necessary to cut the individual strips to certain forms; this I considered impractical. The checks that develop can be filled with the usual putties or pastes but, as plywood, the job would not be countenanced by any scrutinizing purchaser.

Regarding the molding of a complete hemisphere of plywood, I infer that this is done by taking several sheets of veneer of the full size and gluing them together in a form, but I have found that the limitations for molding in this manner are so great that I abandoned all thought of molding in compound curves by pressing the separate sheets of veneer together and allowing the glue to set in the mold. Checks or splits in the face veneer are invariably obtained if the compound curves are appreciable.

MR. OTTINGER:—The paper did not clearly convey to me that it referred entirely to the molding of plywood that had first been formed into flat sheets. This, combined with the statement that extreme warped surfaces must continue to be made of steel or aluminum, indicated a limitation to the use of plywood that does not exist.

I feel that plywood will be used almost exclusively for automobile body building, the body builder buying large panels in sheets. Such parts of the body as have compound and extreme curvatures will be laid up wet. Several body builders are using this method at present.

As to molding a complete hemisphere, I have made several of these in various ways. They have been practically free from surface checks. I overcame these by using thin veneers of high density in one case, but my most successful result was accomplished by cutting and taping the veneers over a curved surface and dipping the center veneers into the glue, instead of putting it through a spreader, as in the case of a flat panel.

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USE OF ALUMINUM IN PRESENT AND FUTURE MOTOR CARS

By Ferdinand Jehle[1]

Although aluminum is the most abundant metal in the earth's crust, it was not until the early eighties that means were discovered for reducing it from its ores in such quantities and at such cost as to make it a commercial possibility. The world immediately began to find uses for this material. Two groups developed; one, assuming for aluminum properties that it did not possess, thought that it would in time replace all other metals; the other, which, reacting from the first-mentioned view due to failures and disappointments, thought it had little use. It was afterward realized that much research was necessary to make aluminum a really commercial metal.

One of the main aims of the automobile engineer is to obtain lightness combined with proper strength. The paper deals with decreasing the weight of automobiles by more extended use of aluminum alloys. The physical properties of aluminum are described in considerable detail and its varied uses are enumerated. A survey is made of recent developments, in old and new alloys and in their use, which includes the evolution of modern methods for handling old alloys, the production of new alloys and a study of the design of parts to adapt them to the use of aluminum.

The discussion of new uses for aluminum alloys in motor cars covers parts made of aluminum at present, such as pistons, crankcases, cylinder-blocks, oil-pans, inlet manifolds, bodies and the like, and parts that will be made of aluminum in the future. The statements are made that it is folly to try to prophesy to what extent aluminum will be used in motor-car construction without limiting the prophecy to a period not greater than one year; that it is safe to expect such parts as wheels and rear-axle housings to be aluminized; and that many developments of aluminum are in progress.

Although aluminum is the most abundant metal in the earth's crust, it was not until the early eighties that means were discovered of reducing it from its ores in such quantities and at such a price as to make it a commercial possibility. The world immediately began to

[1]Dynamical engineer, Aluminum Manufactures, Inc., Cleveland.

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find uses for this material. A. E. Hunt, president of the Pittsburgh Reduction Co., in an article entitled Aluminum, Its Manufacture and Uses from an Engineering Standpoint, which was published in the *Journal of the Franklin Institute* in 1892, states

> In recent years two groups have developed: (*a*) Those who, assuming properties for aluminum it did not possess, thought that it would in time replace all other metals, and (*b*) those who, reacting from the first view, due to failures and disappointments, thought it had little use

It is surprising that some of the hopeful ones did not propose to mold up the clay banks into buildings and railroads and turn on the electric current and produce aluminum structure in situ. It did not take many years for the condition to change. Those who thought that the whole aluminum question had been settled soon began to realize that much investigation and research were necessary to make aluminum a really commercial metal, and those who thought that it had little use saw their error.

In 1896 the *Horseless Age* published an article entitled Aluminum in Motor Vehicles, which is so interesting that I shall quote from it.

> The horseless age is fortunately contemporaneous with the age of aluminum and this latest discovery in the metal industry is likely to play an important part in the development of the motor-vehicle industry. Lightness and strength combined are the great desideratum in metal vehicle construction and as aluminum alloys weigh only one-third as much as iron of the same bulk, it will be seen that the metal is admirably adapted for the purpose

The interesting fact in connection with this article is that it appeared in one of the very early issues of the first technical automobile paper in the English language. At the time of its publication it was undoubtedly considered a prophecy, but today we know that it is quite true. One of the main aims of the automobile engineer is to obtain lightness combined with proper strength. This is clearly shown by many papers and expressions of opinion in the TRANSACTIONS of our own Society. At all meetings at which papers on the Ideal Car, or similar subjects such as the Symposium on the Future Passenger Car, were presented and discussed by the member-

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ship, as at the last Summer Meeting, the one thing generally common to all discussions and papers is that lightness is desirable. It is very true that the different speakers would lighten cars by various methods, some by using a light-weight wood construction, others by employing pressed steel and some by the more extended use of aluminum alloys. This paper deals with the last-named method.

Physical Properties

In the early period of aluminum, its use was considerably hampered by its lack of strength. The tensile strength of pure aluminum is about 13,000 lb. per sq. in. Since this is not enough, alloying with other metals, such as copper, was resorted to. The tensile strength of aluminum alloys was at first very uncertain. That of the well-known No. 12 alloy has been given for a number of years as 20,000 lb. per sq. in. In standard test-bars this figure was obtained, but in regular production it could not be relied upon. Even during the war it was not found possible to hold all foundries to this figure and the Liberty engine specifications had to be lowered to 18,000 lb. per sq. in. For many purposes this strength is sufficient. Without question it was the uncertainty of meeting any specifications that was responsible for limiting the use of aluminum alloys to parts that were not subjected to the highest stress. We therefore find aluminum used only for ornaments, cover-plates, oil-pans and similar articles, for many years. Considerable time was, of course, required for those interested to realize that the handling of the metal in the foundry was quite as important as the composition of the alloys. Then technical control of melting and pouring, as well as of mixture, was installed in certain well-organized foundries. Nor would the control of these important factors guarantee results if pattern equipment were not suitable. Morris Percheron in an article in *L'Aerophile* entitled The War's Influence on Aeronautical Construction in Europe and America, under the heading of aluminum castings says

> American engineers have actually made a science of aluminum casting, where success today is based on the disappointments met with at the outset, great progress having been made if one compares the first foundry experiments with the complicated work of today. The "chance" method of casting does not lead to the produc-

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tion of sound pieces either in general or particularly in the casting of aluminum, and herefrom ensues the great variation in the quality of castings

With adequate technical control in our foundries, 20,000 lb. per sq. in. can be obtained and maintained in the straight copper-aluminum series of alloys in which No. 12 is classed. If this figure can be relied upon, it is entirely suitable for automobile engine parts that have commonly been made of aluminum heretofore, including oil-pans, crankcases and even cylinder blocks. A tensile strength of 20,000 lb. per sq. in. is, however, not sufficient for many purposes, and stronger alloys are now available. In this connection I refer to a product of our laboratories. It represents the result of exhaustive research of both the aluminum-copper and aluminum-copper zinc series. Later in the paper this will be discussed more in detail.

Tensile strength is not the only physical property of importance in motor-car construction. If the material is to be used for any structural purpose, it must have rigidity. The rigidity depends upon the modulus of elasticity which for aluminum alloys is 10,000,000 while that for cast iron is 20,000,000 in round numbers. This means that with a cast-iron and an aluminum-alloy beam of the same dimensions, it will take twice the load to deflect the former that is necessary to deflect the latter an equal amount. If we stop our comparison at this stage, we shall immediately decide against the use of aluminum alloys as a structural material. We must not forget, however, that the iron beam weighed approximately two and one-half times more than the aluminum one. Let us see what results we obtain by making both beams of the same weight and by distributing the metal so as to gain the greatest possible advantage. This would naturally mean that we make the aluminum beam two and one-half times deeper than the cast-iron one. The deflection varies inversely with both the modulus of elasticity and the cube of the depth. Therefore, the deflection of the aluminum beam is to the deflection of the cast-iron beam as $20{,}000{,}000 \times 1^3$ is to $10{,}000{,}000 \times 2.5^3$. We thus find that the deflection of the cast-iron beam is practically seven times that of the aluminum-alloy beam. Inversely, the aluminum-alloy beam is seven times more rigid than the cast-iron one.

We now determine how heavy the aluminum-alloy beam must be made to be as rigid as the cast-iron one. If

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D = the depth of the aluminum-alloy beam and the depth of the cast-iron one be taken as unity, along the line of reasoning already stated, we get

$$\frac{20{,}000{,}000 \times 1^3}{D^3 \times 10{,}000{,}000} = 1, \text{ hence}$$

$$D^3 = 2.00, \text{ or}$$
$$D = 1.26$$

The aluminum-alloy beam will be about one and one-fourth times deeper than the cast-iron one. It will weigh 1.26 ÷ 2.50 or approximately one-half as much as the cast-iron one. We therefore get just as much rigidity from an aluminum-alloy structure as we do from a cast-iron structure at one-half the weight, provided the metal is distributed correctly. Bearing this in mind, there is certainly no better way of lightening engine crankcases than by making them of aluminum alloys. In doing so great attention must be paid to the proper distribution of the metal. Too often the problem of material and material distribution is not given proper consideration when the layout is first made.

The ductility or the elongation of a material is sometimes of importance. The percentage of elongation for cast iron is very low, being approximately ½ per cent. The ordinary casting aluminum alloys have an elongation of about 1½ per cent, whereas certain recently developed alloys run as high as 5 per cent without any reduction in tensile strength. This, of course, is decidedly an advantage over cast iron.

Strength, ductility and rigidity are not the only requirements of a metal, especially one that is to be used in a gasoline engine. An internal-combustion engine is a heat engine and one of its duties is to waste as efficiently and as easily as possible that heat which cannot be turned into power. A metal with a high heat conductivity is therefore desirable. The conductivity of aluminum at ordinary temperatures is about three times as great as that of cast iron. This at once recommends a material for such parts as oil-pans and water-jacket walls. At first it would seem that if a piston or cylinder-head, for example, were made out of a material having a high heat conductivity, large power losses would be brought about. It so happens, however, that the skin resistance or surface resistance to heat is about the same for all metals. The heat-flow into the piston or cylinder-

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head is therefore largely determined by the exposed area. Having once entered these parts, the heat is more rapidly conducted out of them, in cases where the parts are made from the material having a high heat conductivity than if they are made out of a metal having a low heat conductivity. We have reason, therefore, to believe that an aluminum piston or cylinder-head will stay cooler than an iron one. That the temperature actually is less in the former case than in the latter is borne out by the fact that less carbon trouble above and below the piston and less trouble with self-ignition are encountered. To answer the requirements of strength at high temperatures, special alloys have been developed for pistons, and still others for such parts as cylinder-heads, in both of which cases the ordinary No. 12 alloy would not be desirable.

Varied Uses

In 1913 a large manufacturer built thirty engines with aluminum cylinder-blocks. These were painted black so that they could not be distinguished from cast iron and sold as the regular product. The operation of these en-

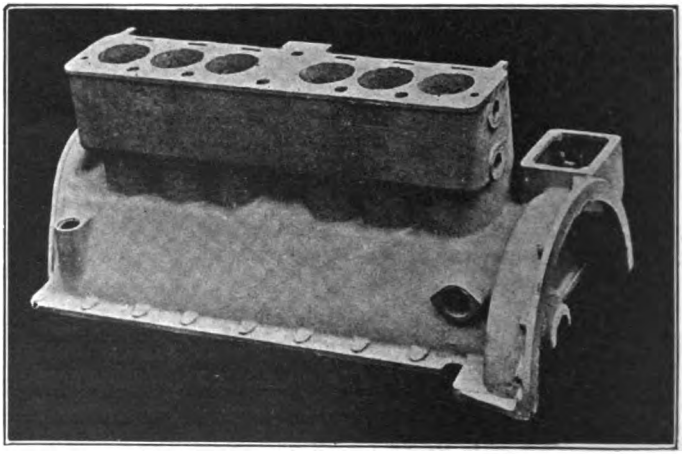

Fig. 1—Aluminum Cylinder-Block

gines was not different from that of the regular product; the engines are still running. I conducted more or less elaborate tests on one of these engines and on a similar one built entirely of cast iron. Accurate measurements

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of the heat losses were made and no differences in these losses were discovered. It is reasonable to expect, however, that in the case of an engine in which the entire combustion space is made of aluminum a somewhat

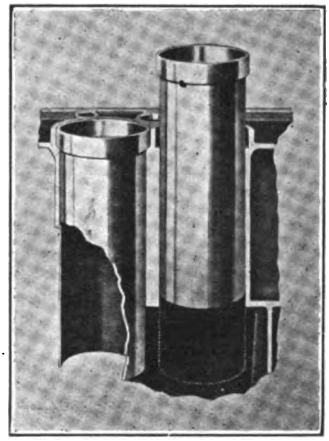

FIG. 2—METHOD OF INSERTING CAST-IRON SLEEVES IN ALUMINUM CYLINDER-BLOCK

higher compression pressure could be used. Fig. 1 shows this cylinder-block and Fig. 2 the method of inserting the cast-iron sleeves in which the pistons operated. A few years after these thirty engines had been built, another company came out with an engine constructed almost entirely of aluminum. This was the first commercial all-aluminum engine. Shortly afterward a third company placed on the market an engine of similar construction. Both of these engines utilized cast-iron cylinder-liners. These were installed similarly to the method shown in Fig. 2. Later the aluminum was removed from around the cast-iron liners, thus allowing the water to come directly in contact with the cylinder wall. This method of installing is shown in Fig. 3. Fig. 4 shows an engine that was designed at our laboratories, involving a large use of aluminum alloys. The parts made of aluminum are indicated by letters and named in the list below.

A history of the use of aluminum in gasoline engines would not be complete without mentioning the Liberty engine. Although this is an aviation engine, I will mention a few interesting comparisons. In this engine 225

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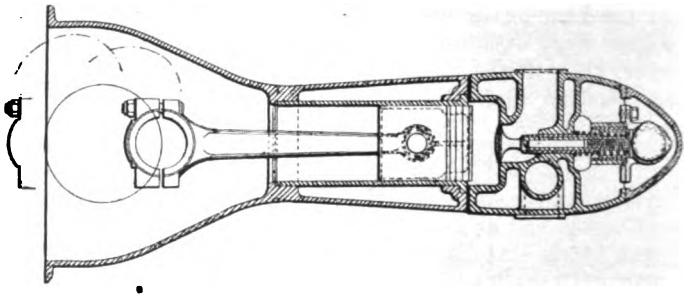

FIG. 3—METHOD WITH WATER IN CONTACT WITH CAST-IRON LINER

lb. of finished aluminum alloys is used. The finished engine weighs about 825 lb. The percentage of aluminum is, therefore, about 27. If all these parts were to be replaced with parts made of cast iron, they would add approximately 325 lb., making the engine weigh 1160 lb. There can be no doubt as to the advantage of reducing the weight of an aviation engine by an amount equal to that just mentioned and, generally speaking, weight reduction is as important in an automobile engine as it is in an aviation engine.

The use of aluminum alloys in motor-car construction need not be limited to the engine. It is quite as important that other parts of the car be made as light as possible. We find today that, due to recent alloy developments, this material can be used to advantage also in transmission cases, differential and worm-gear carriers, fans, radiator headers and shells and a great variety of other places. My company alone makes castings for something like seventy different parts used in motor-car construction. This includes cast aluminum bodies, which require still another type of alloy capable of being cast in thin sections of large area and embodying toughness and ductility. Cast aluminum has certain advantages as a body material. It is light, strong and presents a hard surface for finishing. Fig. 5 shows a cast aluminum body complete with the exception of upholstering and paint.

RECENT DEVELOPMENTS

I shall now take up the different developments made in the old and the new alloys and in their use within the last few years. These developments may be divided into three main divisions.

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(1) Development of new and better methods for handling old alloys
(2) The production of new alloys
(3) A study of the design of parts to adapt them to the use of aluminum

Progress along the lines coming under the first division has already been discussed. They include the controlling of the melting and pouring temperatures in the foundry, and the making of routine physical tests, routine chemical analyses, etc.

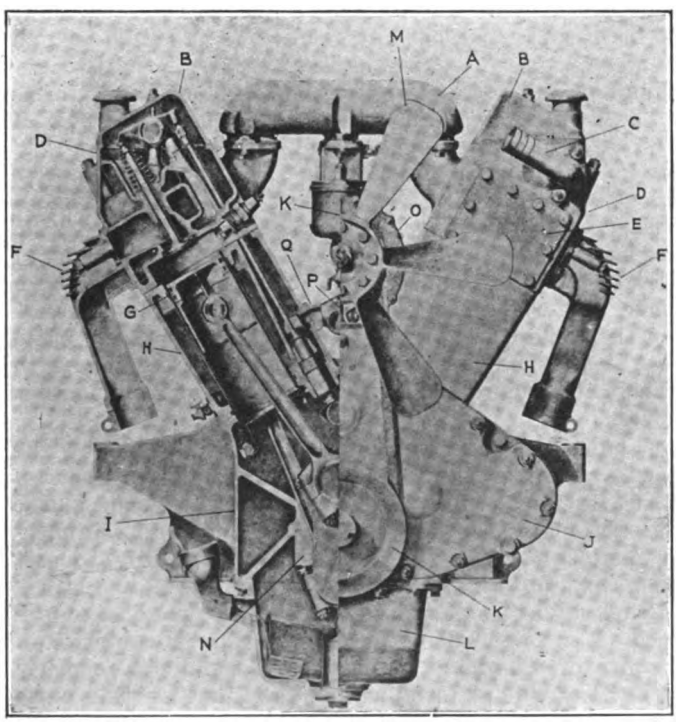

FIG. 4—ENGINE IN WHICH ALUMINUM IS USED TO A LARGE EXTENT

A—Intake Manifold
B—Cylinder-Head Cover
C—Cylinder Water Outlet Elbow
D—Cylinder-Head
E—Cylinder-Head End Cover
F—Exhaust Manifold
G—Piston
H—Cylinder
I—Crankcase
J—Timing-Gear Cover
K—Fan Pulley
L—Oil-Pan
M—Fan
N—Crankshaft Bearing Caps
O—Water-Pump
P—Fan and Water-Pump Bracket
Q—Cylinder Water Inlet Elbow and Tee

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Alloy development has progressed to a large extent in the last few years. Having arranged foundry practice so that a physical specification of the existing alloys could be continuously met, it was only natural that our energies should be turned toward creating new alloys which would meet different requirements. As previously stated, an aluminum alloy having a tensile strength of 20,000 lb. per sq. in. can be used for nearly all purposes for which cast iron is used, so far as strength goes. There are many parts, however, which are today made of malleable iron, steel castings and mild carbon steels, which an alloy of this strength could not replace. Many of these parts could advantageously be made lighter and to accomplish this it was necessary to develop a stronger aluminum alloy. The alloy developed by our laboratories to meet these requirements has a tensile strength of 27,500 lb. per sq. in., an elongation of 4.5 per cent and an impact value of 1.96 ft.-lb. Comparing this with the values for another alloy similar to the well-known No. 12, which has a tensile strength of 20,000 lb. per sq. in., an elongation of 1.5 per cent and an impact value of 0.76 ft.-lb., it is evident that much progress has been made. All these increases are at the expense of increasing the weight from 0.103 to 0.106 lb. per cu. in. I feel that this alloy represents the best that can be done with either the aluminum-copper or aluminum-copper-zinc series.

I advise caution against misinterpretations of the figures given. We must not take the 37.5 per cent increase in tensile strength to mean that we can reduce the sections of the castings by that amount. Thinness of sections is generally limited by the ability to cast them and, for the time being, the thickness of castings is generally as small as it is commercially possible to produce. A stronger alloy, therefore, means an extension of the use of aluminum to parts that could not formerly be made of this material, rather than that existing parts can be made very much thinner. Again, strength is not the only requirement. While both of the alloys already mentioned retain their strength at ordinary temperatures, at the higher temperatures this drops off rapidly. Another alloy is therefore necessary for such parts as pistons and the like which are subjected to high temperatures. We have developed and used for several years an alloy that will withstand higher temperatures. Its strength when cast in permanent molds is 28,000 lb.

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per sq. in., while the impact value is 0.58 ft.-lb. and the elongation about 0.5 per cent. The weight is 0.107 lb. per cu. in. Pistons cast in permanent molds are superior to those cast in sand. When cast in sand the tensile strength for this alloy is less than 27,500 lb. per sq. in.

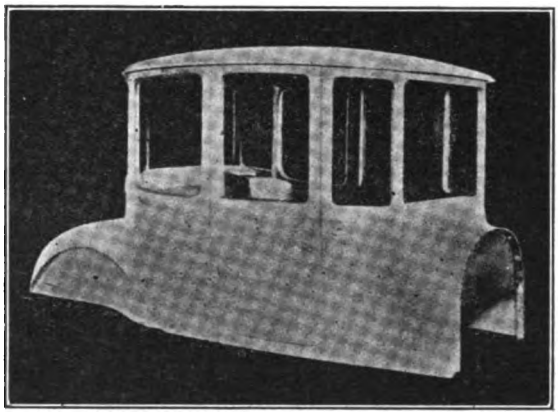

FIG. 5—CAST ALUMINUM BODY

It was necessary for us to develop also an alloy that could withstand a great amount of pressure. The alloy developed to meet this requirement has a tensile strength of 19,000 lb. per sq. in. and weighs 0.107 lb. per cu. in. It can be used for water-jackets and similar parts. Where it is necessary to use an alloy in a place where both pressure and temperature must be withstood, it is necessary to make a special alloy which embodies the properties of the two already mentioned. Cylinder-heads come under this classification. This information is given in the table on page 896.

In designing some particular part to fit the requirements of aluminum you, as engineers, can give the greatest assistance. Do not design a part and then select the material. If an aluminum alloy, on account of lightness or high heat conductivity, would particularly adapt itself to a part, consult someone who knows about such design. The history of the aluminum piston is rich in evidence proving the correctness of this advice. The aluminum piston is here to stay but we know that all experience with it was not pleasant. About 75 per cent of the trouble was due to the tenacity with which en-

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gineers clung to the design used for cast-iron pistons. We have overcome this and today we design aluminum pistons. The experimental work necessary to establish a satisfactory design for a piston was great, but the effort to sell it to engineers was even greater. Formulas for the design of pistons, for clearance, etc., have all been worked out and are available.

New Uses for Aluminum Alloys

The physical properties of the alloys in the table given have made possible the use of aluminum for parts not before constructed of aluminum alloys. Axle housings have been cast from one of these alloys and excellent results obtained. Fig. 6 shows a 3-ton truck rear-axle housing being tested. A housing of similar design but made from cast steel was also tested and it is interesting to compare the results. The aluminum housing weighed 90 lb., while the steel casting weighed 175 lb. Under a pressure of 6 tons the latter had a permanent set of ½ in., while the aluminum one showed none. Tests on the steel housing were not carried beyond this point. At 7 tons the aluminum housing had a permanent set of 3/64 in. and failure occurred at 9½ tons.

This same material has been used for truck wheels

Alloy	Tensile Strength of Sand Castings, lb. per sq. in.	Impact Values, ft.-lb.	Elongation in 2 In., per cent	Weight per Cu. In., lb.	Use
Lynite 112	20,000	0.76	1.5	0.103	Ordinary castings like oil-pans, etc.
Lynite 145	27,500	1.96	4.5	0.106	Castings where greater strength is required, rear-axle housings, wheels, etc.
Lynite 122	28,000*	0.58	0.5	0.107	Castings used at high temperatures, like pistons.
Lynite 109	19,000	....	....	0.107	Pressure castings, like water-jackets, etc.

*Cast in permanent molds.

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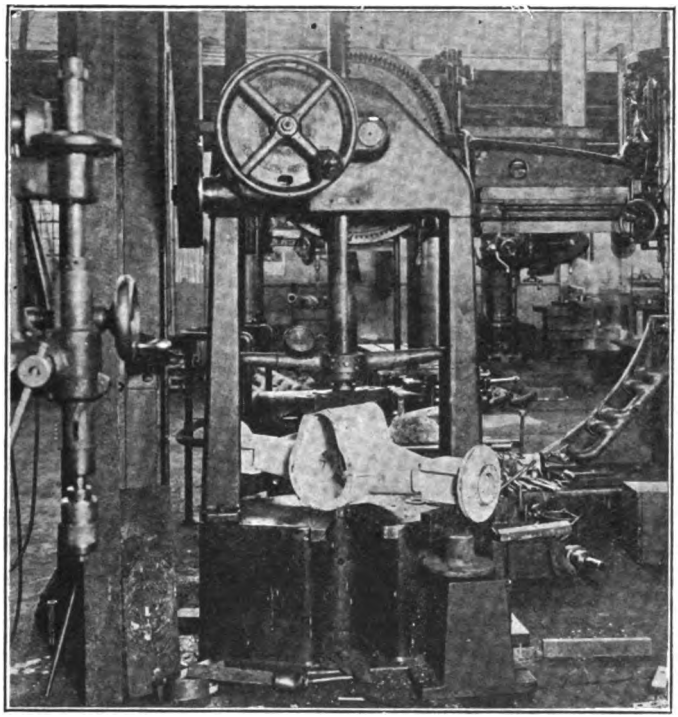

FIG. 6—THREE-TON TRUCK ALUMINUM REAR-AXLE HOUSING UNDER TEST

also. Several trucks equipped with aluminum disk wheels were tested at the Rock Island Arsenal. The test consisted in mounting the truck on drums which were connected to brakes for absorbing the load when the truck was running. Cleats were placed every 90 deg. on the drum. The truck was operated at a speed of 15 m.p.h., which meant that the tires were struck about 260 times per min. by the cleats on the drums. The impact was sufficient to raise the truck 1½ in. from the drum and also to result in breaking a number of parts on the truck by vibration. The test was equivalent to 500 miles and the wheels were all in good condition when it was completed. Each of the aluminum wheels used in this test weighed 82 lb., while the original steel wheels weighed 248 lb. each, making a total saving of weight of 664 lb.

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The use of aluminum alloys in motor cars seems to divide itself into two sections

(1) Those parts made of aluminum at the present time
(2) Parts which will be made of aluminum in the future

To the first class belong such parts as pistons, crank-cases, cylinder-blocks, oil-pans, inlet manifolds, bodies, etc. It would be folly to try to prophesy to what extent aluminum will be used eventually in motor-car construction without limiting the prophecy to a period not greater than one year. At this time it is safe to expect such parts as wheels, rear-axle housings and the like will be aluminized. Many developments along different lines are in progress.

THE DISCUSSION

QUESTION:—Have you had any experience with Duralumin? The advertisements give physical properties exceeding any you have mentioned.

MR. JEHLE:—Duralumin is a rolled product. It is not a casting alloy. The alloys I have mentioned were all casting alloys. The tensile strength generally given for Duralumin is about 60,000 lb. per sq. in. We are confining our present activities to making castings and studying casting alloys.

E. W. WEAVER:—I have been told by people using aluminum cylinder-blocks that it was necessary to give them a Bakelite coating to make them hold water. Is that practice general?

MR. JEHLE:—We treat some castings to protect them against leaks. Sometimes the coating given them performs the additional purpose of protecting the casting against corrosion. The difficulty with leaks is greater in experimental castings than with castings made in regular production. If the first casting is porous it can very often be remedied by providing proper pattern equipment.

QUESTION:—How does the wear of an aluminum piston compare with that of a cast-iron piston?

MR. JEHLE:—The wear is about the same if both are operating in good cylinders and under good conditions. Wear depends upon the nature of the surfaces and the lubrication. If the conditions are equal there is no difference in wear.

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QUESTION:—What is the least thickness you would recommend for water-jackets and water piping, to prevent leakage?

MR. JEHLE:—That depends largely upon the design. A 3/16-in. section can be cast, but one much thinner is not practicable. If such a section is cast against one of ½-in. thickness, this may cause trouble. The question of thinness of section is not only in regard to the thinnest that can be cast, but also depends upon how equal all the sections are. If all are made thin it is easier to get a good casting than if some sections are thin and others very heavy. A head with complicated water passages cannot be cast as thin as a flat plate.

QUESTION:—What work has been done with aluminum in place of cast-iron cylinder-heads, and what compression pressure can be used?

MR. JEHLE:—I have no test results or figures showing exactly how much the compression can be increased by the use of aluminum heads and pistons. It is, however, a fairly well-established fact that preignition does not result from the heat of compression alone; if it did, the compression in all engines would be the same. Accordingly, preignition must be caused by some local hot-spot. If that spot is on the piston or the cylinder head, this can be remedied by using a material such as aluminum which is a better heat conductor.

QUESTION:—Is the bearing for the pin in the piston?

MR. JEHLE:—We make pistons both ways. We must make them as our customers want them, but we recommend that a floating pin be used, free in both the rod and the piston. By a floating pin I do not mean a loose one, but one which can be lightly tapped into place. If the pin has much clearance when cold, it will have more clearance when hot. Our experience has been that a floating pin in both members is superior to one held in either member. I would rather hold the pin in the rod than in the piston.

QUESTION:—Referring to wrist-pin fastenings, do you put a ring around the wall?

MR. JEHLE:—There are various methods of fastening. I prefer the small spring-ring in the end of the wrist-pin hole, if care is taken to sink it to more than one-half its depth into the aluminum. If this is not done there may be a wedging action that breaks the aluminum.

QUESTION:—Is aluminum ever heat-treated?

MR. JEHLE:—I understand that you refer to heat-

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treatment for strength. We do heat-treat some castings, such as pistons. We can regulate the hardness somewhat. Sometimes a piston may increase in size while it is in the engine, but we can do this ahead of time by heat-treating. However, I believe the strength is not increased.

QUESTION:—When aluminum is used in cylinders, is it necessary to season as in the case of iron cylinders?

MR. JEHLE:—Yes, it is a good thing. It would be well, I feel, if all the users of aluminum would do just the same with it as with cast iron, but it is hard to get them to believe that. Referring to the question of growth, this can be brought about artificially by a higher or a lower temperature, if the casting ages long enough and casting strains are thus relieved.

QUESTION:—I understand that in 1917 some Californian aeronautical firms were building four and six-cylinder experimental engines and that they experimented with aluminum valve seats. How did they stand up?

MR. JEHLE:—We now have an engine running that has aluminum valve seats, but thus far, for commercial purposes, we have been contented with cast-iron or bronze seats. A bronze seat is satisfactory, either cast or screwed in. For the inlet valve I think the aluminum seat would be satisfactory; but for the exhaust-valve I am not so certain. We ran an engine for several hours and it apparently stood up well. We prefer to cast in the bronze seats. The coefficient of expansion of bronze is nearer that of aluminum than that of cast iron.

QUESTION:—Can the toughness of aluminum, when it is to be used in place of malleable iron, be increased?

MR. JEHLE:—Aluminum alloys can in my opinion be used in every place where malleable iron can be, in regard to both strength and elongation. The strength and elongation of malleable iron vary over a wide range. Just how these can be controlled I do not know. I think our alloy having a tensile strength of 27,500 lb. per sq. in. can be used in every place where malleable iron is used. With a tensile strength for malleable iron of over 30,000 lb. per sq. in. and that for aluminum over 27,500 lb. per sq. in., we could still make a part of aluminum, having half the weight, by making the section thicker.

ALUMINUM PISTONS

QUESTION:—Is it now possible to design an aluminum piston? How is this done? What has been the past experience?

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MR. JEHLE:—The aluminum piston question is complex. We first made the pistons too light, with heads about 3/32 in. thick and the walls of about this same thickness. We took too much advantage of lightness. We found that we had to use more metal. Then we were a long time finding out the proper clearance. We tried to run pistons with too small a clearance. One of the best examples of aluminum pistons, I believe, is found in the Liberty engine. This piston was not as light as we could make it; it weighed about 3 lb. and had a head about 3/8 in. thick. We now have several formulas, based upon the heat that must be conducted from the pistons into the water-jacket, for calculating head thickness, etc. We get a certain amount of heat in the piston-head which depends upon the exposed area and we must provide enough metal to dissipate it. The exact duplicate in cast iron would weigh two and one-half times more than the Liberty piston. Since cast iron is three times a poorer conductor of heat than aluminum, three times as much metal must be added to give it the same conductivity. This would produce pistons weighing seven times as much, or 21 lb. We are now basing piston calculations on Liberty engine performance, making an allowance for the fact that the horsepower output per square inch is less in automobile than in aviation engines. The next important thing to be settled is how much clearance to give pistons. This depends largely upon the individual engine, but we have been successful in devising a formula that gives a good starting point for tests. We find that if we allow 0.0006 times the diameter of the piston squared, we get about the correct clearance. That may be a trifle too much or we may find that a trifle more is necessary. Then comes the question of ring fits; they should of course be just as close as possible in the grooves. If a ring is loose when cold, it will be looser when hot.

QUESTION:—It is said that the Franklin company is using aluminum pistons very successfully.

MR. JEHLE:—The Franklin company is using aluminum pistons. Of course, the clearance formula I gave must be modified in an air-cooled cylinder. There is a different condition in air-cooled from that in water-cooled engines.

QUESTION:—If aluminum can stand compression, why use a cast-iron sleeve in an aluminum block?

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MR. JEHLE:—That is a question of bearing surfaces only. Cast iron seems to be, as far as we know, the only metal that works well as a bearing when both parts are made of it. We may later be able to get an aluminum alloy that will run successfully on another aluminum alloy, but to date we have not found it.

QUESTION:—Is the coefficient of heat expansion the same in all aluminum alloys?

MR. JEHLE:—It is very nearly the same. The expansion of aluminum alloys is very close to that of the expansion of pure aluminum, so far as we know now. While we may gain a small percentage on one alloy it really does not amount to much. Even if we found an alloy that would expand 10 per cent less than some other, 10 per cent of say 0.007-in. clearance is not within manufacturing limits. If we could find an alloy that would cut the expansion one-half, it would be worth while.

A. W. HUBBEL:—What are the objections to the use of aluminum pistons? We have done much experimenting in England with the aluminum piston. We have had some trouble, the chief one being piston slap.

MR. JEHLE:—The fact is that the definition of piston slap is quite elastic. I have known it to cover everything from a slight tapping of the piston to the noises in the rear axle. Nevertheless there is such a thing, and when pistons are larger than 4 in., it becomes more serious. Piston slap is one thing we must overcome. Clearance, of course, is what brings it about. We find, however, that in pistons of not over 3¾ in. in diameter, it is not serious if the wrist-pin location is in the center of the bearing surface and the clearance is kept close. I do not mean the clearance given on blueprints, but that actually found in the engine. Strange to say, therein lies a difference. I have taken pistons out of new engines and so have come into possession of new pistons that actually measured more at the top end than at the bottom of the skirt. Tapering pistons is good practice and to a certain extent overcomes slap, but we have to taper them in the other direction. Now we find there are two ways of tapering pistons; one, a straight taper from the skirt to the top; the other, to make the piston straight part of the way and then taper it, which I believe is the better method. This has to be resorted to in large pistons. The majority of the cars use 3¾-in. pistons and we do not have much trouble with pistons of that size.

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QUESTION:—Why have the pin tight in the piston?

MR. JEHLE:—The wrist-pin hole gets larger and the clearance between the pin and its bearing will be larger when the piston is hot than when it is cold, but the methods for fastening a pin in a piston are difficult. From tests, I believe the best way to put in a pin is to let it float in both members. Put it in tight in the piston; make it a tapping fit so it is tight when the engine is cold. Recently I put in a set of pistons in which the pin was held by pushing a cotter-pin through a hole in the pin and wrist-pin boss. The cast-iron piston was held that way and they did not want to change the design. We put the pistons in and when we took them out five of the six cotter-pins had been broken. In cast iron that fastening might have been successful, because the pin would have expanded as much as the piston, but with aluminum the piston expanded away from the pin which became loose and the cotter-pins sheared off.

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DETROIT SECTION PAPER

THE AUTOMOTIVE SITUATION IN THE ALLIED AND ASSOCIATED COUNTRIES

The author describes a rapid trip through England, France and Italy, and visits to various automobile plants, touching upon some of the important affairs connected with the automobile industry in February and March, 1920, when conditions were in process of stabilization after the war. Following comments upon freight and passenger transportation in Liverpool, London and Paris, he describes the Conference of Inter-Allied Automobile Industries, at Paris, and its activities relative to standardization, import duties and other important matters. Automobile factories in France and Italy, including the Berliet, Fiat, Isotta-Fraschini and Renault, are referred to, methods of production therein being commented upon.

Europe as an automobile market is discussed, comparisons being made of the number of automobiles per capita now in use in England, Belgium, France and Italy, combined; the United States; England; France, Italy and Belgium; in connection with population statistics. The author's opinion is that European manufacturers will never fully develop their own potential market and that it rests with American manufacturers either to make cars in Europe or to make them in this country and export them. In conclusion, labor conditions are mentioned in general terms.

At a meeting of the Detroit Section, C. C. Hanch, general manager of the Maxwell-Chalmers Corporation, and H. E. Coffin, vice-president and consulting engineer of the Hudson Motor Car Co., spoke on the condition of the automotive industry in the allied and associated countries. Mr. Hanch went abroad after the signing of the armistice in November, 1918, to study conditions and make a report on them.

ADDRESS OF C. C. HANCH

I shall describe a rapid trip through England, France and Italy and visits to some of the automobile plants,

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with the automobile industry.

I landed in Liverpool last February. The people were then just beginning to come out of the war cyclone cellar. They did not know the war was over until then. One could form no conclusions or have an intelligent opinion on conditions over there prior to that time. The first thing that struck me in Liverpool was that an enormous shipping business was being carried on with practically no motor trucks. On the contrary, in spite of the length of the war, I saw great quantities of magnificent teams of horses in the large industrial cities of England. In going from Liverpool to London, I did not see a single freight car that would hold more than one full-grown automobile or truck. This gives an idea of our comparative situation from a shipping standpoint.

In London, at that time, there were perhaps 10 per cent enough taxicabs to supply the population, and the drivers were not very anxious to work. If it was lunch-time it was hard to get any service. On the contrary, in daytime, the bus system of London gives splendid service. I would like to see the equivalent of the London buses in more streets of our own cities. They would be of great assistance to our present overworked transportation systems. One impression that I received in London was that in one drive it required an hour and three-quarters to get through traffic in an automobile, a distance of probably two blocks. That situation occurs at certain hours daily, due to the almost exclusive use of horses, big drays and very light loads, at low speed.

In Paris I was not dependent upon taxicabs, but the same situation exists there as in London. The taxicab drivers were indifferent and reckless. There were not over 25 per cent enough taxicabs to supply the city, and they were largely old two-cylinder Renault cars. The drivers were getting $8 per day in gold at the time, being paid upon the basis of 40 per cent of the receipts and having to buy their own gasoline. This was in March. I noticed also in Paris the total absence of local traffic rules, although the American military police had a semblance of rules for American military automobiles. People ordinarily drive as they please. It is a habit of Paris taxicab drivers to go about 25 m. p. h. and turn sharp in the street without giving a warning signal. Consequently, wrecks in the streets of Paris were frequent.

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My purpose in going to Paris was to attend the Conference of Inter-Allied Automobile Industries. There were delegates from England, France, Belgium, Italy and the United States. There has been an international organization over there for a number of years of automobile industries, formerly including those of Germany and of Austria. After the war delegates from the United States were invited to take the place of the former members from Germany and Austria.

The first day no business was done. The second day they began work, but had only three or four topics. One was the international relation of automobile shows. We found that the dates of the Paris, London, New York and Chicago shows did not conflict; it was agreed to establish those dates permanently and that exhibitors should be admitted to the shows upon reciprocal terms. Whatever terms we imposed upon the exhibitors from France and England, they will impose upon us in Paris and London. They desired to have their show rules adopted throughout the world, but I think they are not applicable to conditions in America. Their rules provide that any manufacturer who has exhibited for three consecutive times at a show, regardless of how many cars he made, is entitled to exhibition space of equal prominence with that of the largest manufacturer. The conference decided to establish a permanent bureau of the organized automobile industries, which simply takes the place of the former organization, leaving out Germany and Austria.

Standardization

The subject of standardization was not on the program and I asked them to put it down for discussion. They accepted the suggestion and I have since learned that they have earnestly made efforts along that line, taking up a number of things which are fairly well standardized in America, such as the mounting of electrical units, battery sizes and locations, electrical terminals, tires and rims. I felt that we in America had everything to gain from such standardization, and that it would be a good thing for them. It was a new idea to them. In the past all of the European manufacturers thought that every part of a car must be unique and different from that of every car made by any other manufacturer. They thought this was necessary to hold their service trade.

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I brought up also the subject, which has since been followed up systematically, of the reduction of annual taxes for the use of automobiles. Taxes are very high. They decided to inaugurate publicity campaigns in England, Italy and France, simultaneously; to reduce the taxes on the use of automobiles and on gasoline. I am advised that they have already accomplished some good results, particularly in England.

Import Duties

The last and most delicate subject handled by the conference was that of embargoes and customs duties. It was at this stage that I became acquainted with the real mental business attitude of the European people, the Latin people in particular. It was the thought of many of those men that America had gone into the war for absolutely selfish purposes. They seemed to have no conception that we had gone into the war for the unselfish reasons which we all feel in our own hearts were our true motives. They felt that we had made great sums of money out of the war before we went into it, and had become immensely wealthy; that they had suffered hardships which we had not borne; and that therefore the equitable thing for the American people to do is to pro-rate the entire cost of the war from the beginning with all of them; cancel all of their debts to us, and cease entirely to compete with them, or to ship any automobiles over there. I could not accept this economic formula and became involved in some discussion over the subject before I left France. Finally, they proposed a resolution on the question of tariffs and embargoes, but upon my insistent objection they rested with simply stating their position.

The statement of their desires in regard to tariffs is that there should be reciprocity on a basis of 10 to 15 per cent ad valorem, provided the tariff charged by any country should not be less than that charged by the country of exportation; and that in no event should the tariff be less than the tariff charged by the country of exportation before the war. This, of course, was a joker aimed at the United States, inasmuch as we had had a higher tariff. Regardless of any tariff we might make in this country, no matter how low, they proposed to interchange between themselves on a 10 to 15 per cent ad valorem basis, and charge the United States not less than 30 to 45 per cent. They have consistently followed

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that idea, because in France they are charging us today 70 per cent ad valorem, c.i.f., and in Great Britain they are charging us 33 1/3 per cent ad valorem, c.i.f. They have not yet made duties between themselves on a basis which discriminates against the United States, but unless there is a firm policy in the United States on the part of Congress they will discriminate against us. It is surprising to know that France is the only nation that has for years enacted discriminatory tariff legislation against the United States.

Automobile Factories and Methods

I left Paris on March 13, and went to Lyons. It had a population of 500,000 before the war, and when the great French industrial city of Lille was taken by the Germans, every one who could went to Lyons. The population was increased from 500,000 to 1,000,000 almost over-night. I do not know what our people who complain of congestion in cities would think if they saw the conditions in Lyons. There is not a sewer in the city. It is one of the livest places in France. The fair which is held there annually to take the place of the former fair in Leipsic, Germany, is a very great demonstration. They have 15 miles of booths for exhibitions, and a very creditable automobile show.

In Lyons I visited the Berliet automobile factory, the second largest in France and very well managed. There are two plants. The old automobile plant is in the heart of the city. The new plant in the outskirts is laid out properly and capable of developing into a modern plant if they can induce labor to work on modern lines. There was no sign of being able to arrive at that result at the time I left.

From Lyons I crossed the Alps into Italy, first visiting the industrial city of Turin, which is the Detroit of Italy. The Fiat factory, the largest in Italy, is located there. My first impression after arriving in Italy was that its entire army was on a leave of absence. I never saw so many soldiers in uniform with no place to go. They seemed to be very happy, but they were not doing anything. In Turin I was brought face to face with the condition we hear so much about, of people not wishing to go to work after the war.

The Fiat company had 40,000 employes during the war. When I was there they had 22,000, and were not

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doing much. They had been working effectively during the war, but as soon as the war was over the men demanded an eight-hour day and various other things. The management gave them the eight-hour day by permitting them to go to work at eight o'clock in the morning and not allowing them to stop for anything until the eight hours were ended. That was an innovation to try to discredit the eight-hour day, but it simply made bad matters worse.

The Fiat factory is the largest automobile plant in Europe. Only one large section of the plant is adapted to economical mass production of automobiles. It will take them two years to complete that section. The remainder of the plant is scattered in seven different separated shops. They have reasonably good foundry facilities, a good forge shop and good machine tools, many of American make, but no sheet-metal equipment whatever. I saw nothing better than a wooden form and wooden mallet for handling sheet metal in any automobile plant in Italy, France or England. I saw nothing in the way of progressive arrangement for machining, although there were a few attempts at progressive assembly. In a few places they had trucks or tanks on a progressive assembling track, but notwithstanding the attempt, they did not have progressive operations. For instance, where they had tried a progressive assembling track, it was not working progressively. It stopped and they finished the job where it stood. It will be many years before European labor will adapt itself to the progressive method in vogue in America, which has resulted in producing the American automobile at its present price and in the present quantities.

At Turin I had my first opportunity to examine critically the types of modern automobile they are producing. Practically every post-war model of automobile in Europe is a 10 or 12-hp. machine, with engine of very small bore and fairly long stroke. They rely absolutely on four gearshifts and a low gear ratio; they change from one gear to another and seem to expect to change gears. That type of car will give reasonably satisfactory results on the good roads they have, and no doubt has advantages where the price of fuel is very high, but would be wholly unacceptable anywhere in America or in any other place in the world where there is heavy going and high ground clearance is required.

The principal plant in Milan is that of the Isotta-

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Fraschini company. It is a beautiful factory but like all the European plants they have lathes in one corner and drills about half a mile away. They turn a piece, carry it a long distance and drill it and perhaps carry it back for another lathe operation. Everything is done by hand, by main strength, and there are no facilities for handling the work progressively.

After returning to Paris I visited a number of industrial plants, among others the Renault automobile plant, the largest in France. I know of no plant in America with which to compare it. It covers much ground. It has no progressive machining or any indication of it; in one wing they attempted progressive assembling of tanks. Their airplane plant is separated from the main factory, and would make a very good modern automobile assembly plant. They were converting it into a body plant at the time I left.

Europe as an Automobile Market

The principal French motor-car factories claim a capacity of 149,000 cars a year. My estimate is that during the twelve months ending July 1, 1920, they will have produced 50,000 automobiles as a maximum. In England, all of the principal plants have a claimed capacity of 63,000 cars a year. I think they can turn out within the same period 40,000 automobiles. The truck manufacturers of England, after four years of continued effort, spurred on by the needs of the war, produced only 13,000 motor trucks in 1918. The entire motor-transport equipment made in England for English use and including purchases in America, amounted to 82,000 vehicles at the end of the war. France commandeered 40,000 automobiles in civilian use at the beginning of the war, and notwithstanding their production and their purchases they had only 50,000 vehicles at the end of the war. The United States in approximately twelve months of effort put 70,000 motor vehicles in use overseas; 66,000 were of our own make and 4000 were purchased abroad.

The population of England, Belgium, France and Italy is 127,000,000; they have 350,000 automobiles, one to every 363 people. The United States has 110,000,000 people; on Jan. 1, 1919, we had 6,000,000 automobiles, one to every 18 persons. England alone has 45,000,000 people and 200,000 automobiles; one to every 225 persons. France has 40,000,000 people and 100,000 automobiles; one to every 400 people. Italy and Belgium com-

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bined have 42,000,000 people and 50,000 automobiles; one to every 840 people. This is in spite of the fact that there are good roads in all these countries.

They have universally treated the automobile as a luxury and trained the public to regard it so. The small low-powered automobile they are making as their post-war design is just as expensive in proportion as was the high-powered car they made before the war. In my opinion European manufacturers will never fully develop their own potential market. It will rest with American manufacturers either to make cars over there or export from this country. On the other hand, if our Government reduces the duty too much, many people in this country will buy foreign cars. There is no question that we would have competition if the doors were wide-open.

Labor Conditions

The labor situation is most important today, not only in the United States but in every country. The productive manhood of Europe was practically taken out of industry and put into the war. There are just two fundamental habits of mankind and they are the habit of idleness and the habit of work. The work habit is the best of all habits and the idleness habit is the most vicious. All other habits are collateral to one of the two named. The effect of four and a half years of war was to inculcate the habit of idleness, notwithstanding that the men were fighting and risking their lives part of the time. They must overcome the habit of idleness before Europe can emerge from labor trouble.

ADDRESS OF H. E. COFFIN

I heard the Earl of Reading make a speech in London recently. His subject was the financial foundations of the British Empire. He concluded that the financial foundations of the British Empire were perfectly secure if British labor would return to work and start quantity production. I think that lack of quantity production is the greatest fundamental difficulty in the world today. There is no use in increasing wages and immediately raising the prices to the American public

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to take care of this increase in wages. That is an endless procedure. So long as American labor holds off quantity production while we have strikes continually and continue to deal in a half-hearted way with the situation, there will be a continual increase in the cost of living. There is no other solution, no other end to the cycle, except a quantity production which will automatically decrease the prices of commodities. We all realize that if there were an over-production of motor-car materials in the course of the next year, there would be a reduction in the price of automobiles. There has never been a time when that principle did not hold true. It is applicable to any other line of commodity supply.

The situation in Europe from a production standpoint is perhaps only what might have been expected. When the European nations entered the war they had no idea of the magnitude of the undertaking. Germany had no idea of it; neither had France or England. Germany estimated that she had stored up, during some years of preparation, enough ammunition to carry the war through. She did not expect the war to continue for more than a brief period of months. As soon as she began to realize the futility of this dream and the munitions began to disappear, she saw, for the first time, the necessity for the quantity production of war materials. There was a time when German munitions were practically exhausted. The Allies experienced the same difficulty a little later. There soon came a necessity for quantity production of all materials that pertain to war. In all the major countries of Europe quantity production was achieved, but under war conditions and therefore under a controlled labor market. These were conditions in which economy was one of the last considerations; the amount of money spent in plant extensions or in the production costs of the commodities was not a first consideration; and where there was no limit on tool equipment or in the use of any other essentials for obtaining the desired quantity production. Previous to the signing of the armistice and immediately following it, European manufacturers boasted that, since they had learned to produce in quantity in accordance with American methods, they would be a greater factor in the world's trade and more active competitors of the United States in the very things in which this country had always been preeminent.

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So-Called European Quantity Production

In November, December and January, representations were made by the British to their trade connections throughout the world, and to a certain extent also by French manufacturers, to the effect that since they had learned the American secret of quantity motor-car production, and had the added advantage of the excellence of European labor, motor cars would be supplied to the export markets at prices far below anything ever yet achieved in European countries. They represented also that the quantities would equal those mentioned in the reports of great American quantity production. As a result, in countries like Australia, dealers were saying to our representatives that they would now deal with the home country, that quantity production had been achieved there and that the era of the cheap motor car of European manufacture had come. Months have passed and the Australian representatives have had notices from their home offices that there has been an increase in the price of motor cars and directing that orders be reinstated upon the basis of the new price. Meanwhile there have been no deliveries. There have been several such notices, the price has returned to about the old pre-war figure and quantity production has not yet been achieved. As a result, foreign representatives are eager to do business again with the American manufacturer. The European manufacturer must now consider questions of financial outlay and economical production; he must deal with a difficult labor factor. Europe's and America's labor problems are intermingled with the subject of quantity production.

The hardship of cancelled contracts which American manufacturers complained of following the armistice, has proved a blessing in disguise. In Europe there was a great fear about throwing labor out of employment and, to guard against this, government war contracts were continued for months after the armistice. In France some manufacturers were producing munitions at a very much higher rate in January and February of 1919, than at any time during the war. The different governments were continuing to pay for all material and the manufacturers were trying to produce as much as possible before the time limit expired. This course of action did keep labor employed, but also caused a very bad reaction. It kept the manufacturing brains and productive power of these countries engaged upon

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work that was in no sense commercial. It involved great waste of material and effort.

Delay in the signing of the Peace Treaty prevented industrial recovery. Manufacturers generally were uncertain as to what the commercial conditions of peace would be, and hesitated to launch new activities until questions of import duty, of finance, and raw material supply could be clearly defined. In short, Europe remained to a great extent under military control. As war contracts finally terminated and plants began to shut down there was a tremendous amount of dissatisfaction and unemployment. In England an allowance of some 28 shillings per week was paid by the Government to all workers who were unemployed. There is no more fertile field for trouble than in a group of unemployed, especially if it is their desire to sow the seeds of industrial unrest and dissatisfaction. I should say that the delay in the execution of the Peace Treaty, perhaps more than any other one thing, tended to bring about the present highly unsatisfactory labor situation in the Allied countries.

American Colonial Export

One interesting development in connection with our trade, as related to the export trade of Europe, is that during the war colonial manufacturers and dealers generally have been forced into contact with American manufacturers and their methods. We formerly heard a great deal to the effect that American manufacturers were not taking care of the colonials as well as were the European firms. There was a constant demand for different types of chassis and body for a long wheelbase, and different kinds of equipment. In fact, the American manufacturer did little that was right. There has been a reversal of form in this connection. The colonial buyers have learned that American products are mainly satisfactory and that American business methods appeal to them after they learn to know American manufacturers. There is a great change of sentiment among them in this respect. I believe that European manufacturers must bring their methods more nearly in keeping with American procedure. But American manufacturers must be careful to cultivate the friendly feeling which has thus been developed, and they must properly and tactfully handle the business which has been built up. Above all else, they must take care of repairs. Ordinary repairs can

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be made promptly on American cars and this feature is making a very strong appeal indeed to all purchasers who are located in foreign countries.

Aerial Development

The British policy is one of insuring coordination between the three arms of defense, which they consider co-equal, the Navy, the Army and the Air Force. They have a separate ministry of the air, dealing with the commercial as well as the military aspects of aerial development. It is their theory that military preparedness in the air can be assured only through the active encouragement of the development of commercial aviation. Lines are being organized from London to India and Cape Town, and England stands prepared today to join with the American Government in the establishing of a transatlantic mail dispatch and passenger service. The transatlantic flight of the R-34 was simply an experiment to gain experience. The R-34 was conceded to be out-of-date in design. They are engaged in the construction of very much larger and better machines. They have developed an interesting system for the transmission of correspondence. It is a system of photographic reduction of business correspondence to postage-stamp size, on one side of the Atlantic, and the reproduction of that correspondence to its original size on the other side. Thus, letters of standard business size will be reduced to tape and carried in miniature overseas. In this way practically all of the transatlantic first-class business mail can be carried by air in an astonishingly small tonnage space.

From a military standpoint, the system planned by England is based upon the theory that the young officers of the war and navy departments of today will constitute the "high commands" of the military and naval forces not many years hence. It is proposed therefore to give the young officers of both services a thorough training in the theory and practice of aerial strategy, so that when they do succeed to high command they will carry with them an accurate knowledge of the possibilities and uses of aircraft. The development of the Air Force had come into its own just before the armistice, and for the first time fleets of 200 and 300 machines were being used in mass formation, for the raiding of ground troops and for the execution of strategic operations far behind the German lines.

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The British policy contemplates the establishment of an Air College similar to our West Point and Annapolis Academies. Their plan calls for the "circulation" of officers of the Army and Navy Departments in considerable numbers through this educational institution, and through some three years of service in the Air Department. They will thus go back later to their own services with a thorough knowledge of aeronautics and a sympathetic appreciation which will insure coordination of the several services. We have had experience enough here since the armistice to show us that there will be no possibility of a definite aerial policy in this country until we have, like the British, a separate department or division of the government, living and dealing constantly with the problems of the air-service development, civil, military and naval. Aeronautics cannot be handled as a side issue as at present. For example, the idea of assigning a cavalry officer, under the present system, to a more or less temporary command in a department as technical and intricate as that of the air, is utterly impractical. The mission of which I had the honor to be a member placed itself squarely on record in this matter, after investigating conditions in Italy, France and England. The American Aviation Mission recommended that the air activities of the United States, civilian, naval and military, be concentrated within the direction of a single governmental agency, created for the purpose, co-equal in importance and in representation with the Departments of War, Navy and Commerce, and that the agency thus created should be charged with full responsibility for placing and maintaining our country in the front rank among nations in the development and utilization of aircraft for the national security and in the advancement of the civil aerial transportation and communication arts.

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INDIANA SECTION PAPERS

THE PLACE OF THE SECTION IN SOCIETY ACTIVITIES

By C F Clarkson[1]

The Sections are very largely the life blood of the whole fabric and organization of the Society. They are the typification and the exemplification of the activities of the Society, through participation in the various kinds of work the Society is doing. The Sections are locally of the utmost professional and social value continuously and constitute a ready organization enabling the Society to accomplish emergency results when necessary. They have such autonomy and independence as they need and can use and are guided by the generous and admirable service of the Section officers. The Council of the Society morally and financially supports the Sections in any thoroughly sound way in which the general moneys of the Society can be expended with proper advantage to the Society as a whole.

While social features are a valuable aid, the Society's real function is the dissemination of engineering knowledge and the Sections should encourage the presentation of engineering information by clear comprehensive summaries of matters already known or enlightenment on matters that probably will be reduced to practice soon. The reputation of the Society must stand on the merit of its publications.

The Society's membership includes practically all the leading and representative designers and producers of automotive apparatus in this country and a large contingent resident throughout the world. Its membership is growing steadily at the rate of at least 1000 high-grade members per year.

Standardization and research work are reviewed and their present trend is outlined. The Society is established nationally, internationally, industrially and in a Governmental way, and is alongside the other and older engineering societies. It is the duty and privilege of the Sections to assist in all the work of the Society. They should proceed in the spirit of the true worker, exemplifying the truth of the doctrine that the best way to help onesself is to help others. The prime reason for the success of the Society is the remarkable cooperation of its members.

[1]Secretary and general manager, Society of Automotive Engineers, New York City.

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The Sections are very largely the life blood of the whole fabric and organization of the Society. They are the typification and the exemplification of the activities of the Society, through participation in the various kinds of work the Society is doing, and in large part in carrying forward the enthusiasm we always have at the Summer and Winter Meetings of the Society.

The Sections are of the utmost value continuously, in a local way, both professionally and socially, and also to the members at large who receive in due course through the publications of the Society the papers and discussions presented at the Section meetings.

The Sections also constitute a ready organization which enables the Society to do almost anything it wants to do on occasion or in emergencies such as we had during the war. This Section, like the others, is local headquarters for any active work on which quick action is necessary.

The Sections are organized by action of the Council of the Society, from time to time, whenever there is a reasonable prospect of permanent success by a Section in an automotive center. We have eight at present, and in addition one organized tentatively at Washington.

Some of the Sections have slowed down, from time to time, for industrial reasons, or on account of conditions during the time of war; but on the whole they have been a great success, and there has been no failure of any kind to carry out their functions that could not have been reasonably discounted and expected.

One point in connection with administration is that it has been thought that there should be in all important automotive centers an organization that is very active in fostering the various things which are near the hearts of a body of men such as this. The policy has been that the Sections should have as much autonomy and independence as they want and can use in the proper conduct of their affairs consistently with the keeping of various permanent records, and considering how busy the officers of the Section are with their own immediate business obligations. There is no more striking feature of the work of the Society than the generous and admirable service of the Section officers.

We have been completing some details of the sectional organization which were started prior to the war. There is a Manual for use by the Sections in the various steps of their work. The bookkeeping methods are outlined

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as simply as possible, to be readily understandable by succeeding governing officers of the Sections.

There is now and always has been a disposition on the part of the Council of the Society to support the Sections morally by all kinds of assistance and financially and in any way that is thoroughly sound and in which the use of the general moneys of the Society can be expended with proper advantage to the membership of the Society as a whole.

Character of Papers Presented

A good amount of attention should be given to the nature of the papers presented at the Section meetings. The social features are valuable in themselves and as helping the other work, but our real function is the dissemination in understandable form of engineering knowledge. The reputation of the Society stands, and must stand, as it always has stood, on the merit of its publications. The Indiana Section, as well as the other Sections, should encourage the presentation of real engineering information, not necessarily of an abstruse nature, in the form of either a comprehensive, clear summary of things that have been known in a general way, or by way of enlightenment on something that is in sight and will probably be reduced to practice soon. Our work is to disseminate reliable engineering knowledge, and anticipate what is to come.

We are fully justified in saying that the Society of Automotive Engineers has in its membership practically all the leading and representative designers and producers in this country of automobiles, motor trucks, farm tractors, airplanes and other aeronautic apparatus, motor boats, and engineers connected with the production of semi-portable internal-combustion units such as farm engines. There is also a large membership resident throughout the world. These men are members of the S. A. E., the Society of Automotive Engineers, formerly the Society of Automobile Engineers, which changed its name in deference to those engineers working in various automotive fields, at the time they joined the Society. You may not all appreciate it, but it was a daring thing for the Society to change its name. It was a broad and in a way a self-effacing action. There have been not only no adverse results but the greatest benefits from the far-sighted step. The decision was clean-cut, most

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timely and very highly effective. No important word in the English language ever went into general use as quickly as or more justifiably than the word "automotive."

As to the cause and explanation of the success of the Society, its growth was forced, in a way, the same as in the case of the automobile industry itself. But the prime reason for the success of the Society is the remarkable cooperation of its members. I have been asked by men working on the staffs of other engineering societies, how we do certain things. The answer is that committeemen appointed by the Society, being actually interested in some real work to be accomplished, assist us in getting ahead on the various matters.

Standardization and Research Work

As to the standards work, which is perhaps the thing that has distinguished the work of the Society of Automotive Engineers from that of other engineering societies, both here and abroad, we certainly have achieved much in the matter of the simplification of material specifications, mounting dimensions and so forth. If the directly traceable benefits of this in money value to the industry be taken as only a small fraction of 1 per cent of the output value of the automobile industry, which is only one of the automotives, it is seen clearly that they represent a very large amount of monetary saving.

The Society has taken the laboring oar in the matter of the solution of the fuel problem, so far as automotive work is concerned. We have held various meetings. The National Automobile Chamber of Commerce has appointed a committee, of which John N. Willys is chairman and other prominent men are members. The American Petroleum Institute has appointed a committee of five to confer with this committee. We have organized also the Automotive Fuel Committee, which is about 100 per cent representative of the associations interested in automotive matters professionally and industrially and of the Government Bureaus.

Some very important work has been going on with respect to securing further screw-thread standardization. The National Screw Thread Commission, made up of government representatives and engineers nominated by this Society and the American Society of Mechanical Engineers, has formulated a very comprehensive and

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valuable report on this subject. The Commission has visited England and talked the various matters over with the Britishers; and also visited France. There is some prospect of international screw-thread standardization, a thing we would not have dreamed possible a short time ago. There is nothing more important in factories than good screw-thread specification and the setting of limits as they should be. Up to a certain point the closer the limits the more economical the manufacture. Intelligent specification and the absolute maintenance of limits are essential. There have been very few men who have claimed to be screw-thread experts, in this country, or abroad. The average practising engineer depends on these specialists, and knows too little about the merits of the question. There are some very important points involved. Right practice can make or break a factory.

There probably will be some development of international aircraft standards. There is an international commission, the organization of which has not been completed, and something should be done in the way of specifying materials and dimensions of parts that can not only be the same but should be the same in various countries. There are in addition broad questions as to factors of safety and so on.

Generally speaking, there has never been a time in engineering society work as important as the present time. We have never had such consideration of the foundations of science, the arts, and sociology and business, as now. This applies peculiarly to the automotive industry. It is more advanced, more successful, relatively speaking, than other industries, more rapidly developed and developing, and clear acting. No man of real intelligence, I believe, is really cock-sure today as to what is going to happen in the general situation. As to the Society in this connection, it is alongside of the other and older engineering societies. It has been established nationally and internationally and industrially and in a Governmental way. It is very clear that the effectiveness, the elasticity, and the flexibility of all the engineering societies, are now under a severe test. There is much that they should do, and that they can do, if they proceed in the right way. They must give the best possible service that they can to the industries, and to the Government. There are certain relations in engineering matters between the industry and the Government that must be clearly understood and maintained.

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It is the duty and privilege of the Indiana Section to assist in all of the work mentioned, and I am sure that it will be willing to do so. The Society of Automotive Engineers illustrates as well as any other organization the truth of the doctrine that the best way to help one's self is to help others. Optimism is peculiarly a matter of viewpoint. An optimist is a man who judges the present by what has happened before. A pessimist makes up his plan in contemplation of an impossible ideal. There is not much in life except the spirit of the true worker. This is the measure of all that has ever been done, or is being done, as well as the measure of what is before us. It is what protects us against political chaos and social insanity. Let us work in that spirit on the matters engaging our attention immediately.

THE ESSENTIALS OF HIGH-GRADE STEEL MANUFACTURE

By W R Shimer[1]

The manufacture of high-grade automobile steels begins with the selection of proper raw materials. The larger manufacturer of today owns and controls his ore, coal and limestone properties and can obtain a uniform quality of raw materials, enabling him to produce finished steel products of uniform quality. The major portion of steel made for the automobile industry today is manufactured by the basic open-hearth process. Crucible and electric-furnace steel is used to a certain extent, when the tonnage is relatively small and special properties are desired.

The physical and chemical charges in the open-hearth process are specified, with comments on the resultant product. The making and testing of steel are described, illustrations of test-specimens being presented. The pouring of ingots is stated as being a most important factor in the manufacture of steel. Steel should be poured into the ingot mold as slowly as possible so that the metal can solidify from the bottom upward, the top remaining molten until the last. Further details of pouring are given and comments are made regarding pipe in bottom-poured ingots, re-

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fining high-grade steels, molds, inspection of the steel blooms and samples for analysis taken from the blooms.

The heat-treatment of alloy steels actually commences with the ingot after casting. After some discussion of this subject, inspection methods are reviewed in considerable detail and practical examples and comments are included. The causes of failure in service are treated at some length. Three specific statements are made relative to the factors determining the sources of steel supply, which the prospective purchaser of large tonnages of high-grade steels should consider.

The manufacture of high-grade automobile steels begins with the selection of proper raw materials. The larger manufacturer of today owns and controls his ore, coal and limestone properties, and, therefore, is in a position to obtain a uniform quality of raw materials, enabling him to produce finished steel products of uniform quality. When it is necessary for a steel manufacturer to purchase raw materials from the market he many times must accept ore, coke and limestone of varying quality, thereby making it difficult for him to produce pig iron of uniform quality with a corresponding quality of steel products.

The majority of steel made for the automobile industry today is manufactured by the basic open-hearth process. Crucible and electric furnace steel is used to a certain extent, but only for very special purposes where the tonnage is relatively small and special properties are desired. These latter grades of steel are expensive and on this account are unwarranted for use for the bulk of automobile parts. The physical charge in the open-hearth furnace consists of pig iron and steel scrap in approximately equal proportions with a certain amount of ore and limestone.

The chemical charge is approximately

	Per cent.
Silicon	0.75 to 0.90
Phosphorus	0.10 to 0.11
Manganese	1.00
Carbon	1.75 to 2.00
Iron	96.00 to 97.00
Sulphur	About 0.070

All of these elements, except sulphur, give the furnaceman practically no trouble, as he can reduce silicon,

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phosphorus, carbon, etc., to any desired percentage. Sulphur is the only element which causes any difficulty and must be controlled by the use of as low-sulphur scrap and pig iron as it is possible to obtain. Due to present labor conditions in the coal mines and to the diverting of proper steel-making coals by the Railroad Administration, the steel maker is very much handicapped and must accept, many times, high-sulphur coal, or none at all, and the sulphur in the steel is increased on this account. There is the old adage that "the effect of phosphorus in steel is up to the consumer and sulphur up to the maker." In other words, phosphorus is a greater hardener than carbon and high phosphorus tends to reduce ductility in the higher carbon steels. Sulphur is considered the red-short element and need not be feared by the consumer as long as the heat of steel forges or rolls satisfactorily and the finished product is free from surface defects.

Making and Testing the Steel

Pig iron is sometimes charged in the open-hearth in the molten condition and at other times in the form of cold pig, steel scrap being used in both cases. Immediately after the materials charged are melted, the furnaceman takes a small quick test from the furnace with a spoon and casts it into a small ingot called the quick-test ingot. This ingot is cooled and fractured and from the appearance of the fracture he judges the approximate carbon content of the bath. Half of this test ingot is then sent to the laboratory, drilled and analyzed for carbon, manganese, phosphorus and sulphur. If the heat is to be nickel steel and nickel-steel scrap has been used, the nickel also is determined from the quick test in order that the necessary addition to meet the alloy requirements can be calculated. Subsequent tests are taken from the furnace by the furnaceman at intervals in the process of refining until the heat is down to the required carbon content, by which time the phosphorus has also been lowered as well as the other elements, and the heat is then ready for the final additions. Ferromanganese is added to the furnace in amounts depending upon the results reported by the laboratory on the last quick test. Ferrosilicon in basic open-hearth steels is added to the ladle, having first been crushed up very fine. The addition is made to the stream of metal coming from the furnace as

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it enters the ladle. Ferrosilicon cannot be added to the furnace as it would attack the basic furnace lining.

Fig. 1 shows a series of fractures of the quick-test ingots taken during the melting of an open-hearth heat, commencing with the one taken immediately after the bath is melted and including the final test. The carbon content as judged by the melter and also as determined by the laboratory is shown with each fracture. It will be noted how closely the carbon can be judged by the

FIG. 1—FRACTURES OF QUICK-TEST INGOTS

Percentage of Carbon as Judged by the Melter				
0.15	0.45	0.60	1.00	1.40
Percentage of Carbon as Determined by a Laboratory Analysis				
0.14	0.43	0.55	0.93	1.34

melter by the appearance of the fracture. The highest carbon test has the finest grained fracture, which becomes more coarse-grained as the carbon content decreases. An experienced furnaceman can estimate the carbon from the fracture with nearly the same accuracy as that of a chemical determination, especially when working with carbon steel heats. It takes an especially well experienced furnaceman to judge the carbon from quick tests, from nickel, nickel-chrome or other alloy steel heats.

When the heat of steel is refined and the desired composition obtained by eliminating some elements and adding others such as manganese, silicon and other alloys to meet the specifications, it is tapped into a ladle. The slag also runs into the ladle, floating immediately to the top of the molten steel on account of being much lighter in weight than the latter. It seems to be the impression of many that microscopic non-metallic inclusions in steel originate from slag in the furnace or the ladle. As evidence that this is not the source of such inclusions, I will cite the following examples:

A number of times after a ladle of steel was empty, at the time when both slag and steel were dripping from

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the ladle nozzle together, a small test ingot, a 2½-in. cube, was taken in an attempt to obtain a small ingot contaminated with ladle slag. The material cast into this small mold solidified the instant the mold was filled. It was found that the upper half of each one of these small ingots was slag and the lower half a solid steel casting, the slag having separated from the steel immediately, on account of its lighter weight. These small ingots were then split, polished and etched and subjected to a very careful microscopic examination over the entire surface and found to be entirely free from slag. Fig. 2 shows such a small ingot after splitting in half and polishing and etching. There were several blowholes in the ingot shown in this illustration whose sides were silvery white, containing no slag. Such evidence as this convinces one that the non-metallic inclusions in steel do not originate from furnace or ladle slag, since the latter separates from the steel as readily as a cork floats on water.

Furnace and ladle slags are composed of oxides of iron, aluminum, calcium, silicon, manganese, etc., while microscopic non-metallic inclusions in steel are mostly sulphides of iron and manganese, and at times very small amounts of silicates of manganese and iron. These latter inclusions are due to foreign matter from the molds or other external source. The sulphide inclusions originate from the reaction which occurs in the molten metal in the ingot before solidification, and become imprisoned during solidification. Their size and quantity increase with the size of the ingot; that is, the larger ingots remain molten longer and sulphides have more time to segregate in them than in the smaller ingots. If the steel in the mold solidified the instant it was cast, there would be no sulphide inclusions of appreciable size, if any. Additional evidence is that non-metallic inclusions in steel contain no lime, whereas furnace and ladle slags always contain lime.

Pouring the Ingot

The pouring of ingots is a most important factor in the manufacture of steel. Steel should be poured in the ingot mold as slowly as possible so that the metal can solidify from the bottom upward, enabling the top to remain molten until the last. The practice of box-pouring produces clean ingots with very little pipe, since by this method two ingots are generally poured at a time, therefore permitting slow pouring; also the pressure of the

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stream from the box is much less than when poured direct from the ladle, and the metal cools from 80 to 100 deg. fahr. when run through a box. Splashing of the stream against the sides of the molds is prevented to a great extent, thereby improving the surface of the ingot as well as the rolling qualities and giving consequent free-

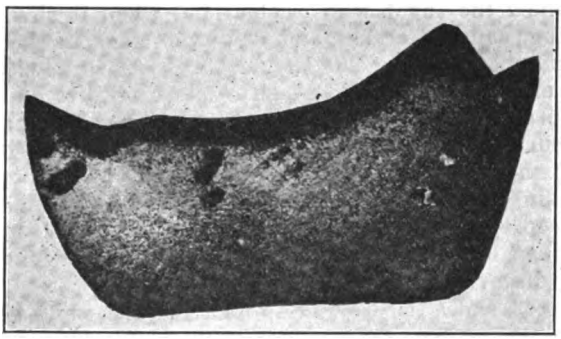

FIG. 2—SMALL INGOT, SPLIT, POLISHED AND ETCHED

dom from cracks and scabs. There are other methods of pouring steel ingots which have advantages. Some manufacturers bottom-pour by teeming the metal into a central runner to which runners are connected to a series of molds and the molds fed from the bottom. This practice improves the surface of the ingot, permits slow pouring and improves rolling properties.

To overcome pipe in bottom-poured ingots it is necessary that the molds be equipped with satisfactory sinkheads to keep the tops molten until the metal in the body of the ingot solidifies. The method of pouring, whether box-poured, bottom-poured, or poured direct from the ladle, depends upon the grade of steel being made and the practice with which the manufacturer has met the most success. Each steel-maker swears by his particular method and obtains good results, as his pouring method is particularly adapted to the grades of steel he manufactures and his organization has been trained to carry on the method successfully.

It is of the utmost importance that high-grade steels be refined with extreme care and that all additions possible be made in the furnace. To be assured that a heat of steel is of uniform analysis, the quality manufacturer

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takes three heat-tests from the ladle, one at the beginning of the ladle pour, one at the middle and one at the end. These tests are analyzed by the laboratory and the heat is not applied if the composition is not consistent throughout.

After careful refining, a good heat of steel can be spoiled after leaving the furnace by casting into dirty or rusted molds or old molds having depressions or cracks in which the ingot will become held when it shrinks in cooling, causing cracks and resultant tears in the ingot when rolled. The molds should always be in good condition and slurried with a wash to clean all dirt and scale and prevent the metal which may splash against the sides in pouring from adhering to the mold surface. With the clean mold extreme care should be exercised in casting and sinkheads should be placed on the top of the molds to keep the upper part of the ingot molten so that the pipe can be retained in the upper part of the ingot and later discarded at the blooming-mill shear.

Fig. 3 shows two split ingots from the same heat of steel, that at the left having been cast with a sinkhead and the other without. The difference between these ingots is evident, the former having much less pipe than the other. The ingots should then be stripped while still hot and charged vertically into the soaking pits within a short time thereafter, there to be heated carefully to the proper rolling temperature and special care taken to soak them through thoroughly before rolling. The ingots are then rolled down on a blooming-mill to about 9 in. square and pass on to the hot shears where the top and bottom discards are cut and the sound portions cut to length for subsequent rolling on the smaller mills. The shearing of the top discard from the blooms is witnessed by an experienced man who can detect by the appearance of the sheared surface whether the bloom is free of pipe, and he instructs the shearman to continue shearing off additional metal until he is absolutely assured that all of the piped steel has been discarded. In the case of steels of a special nature or of a composition having a greater tendency to develop pipe, the ends of the cold blooms from such heats are cold-fractured in the billet yard to give assurance of their freedom from pipe.

When cold the blooms are carefully examined for surface defects such as seams, tears due to ingot cracks and scabs resulting from poor molds and splashing of the metal while pouring. With good practice there should

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be but few of these defects. All of the surface defects are chipped out carefully, first, with a U-shaped gouge that produces, at times, rather deep grooves in the bloom which are then flared out on both sides with a flat chisel to prevent any lapping of such a groove in the subsequent rolling operations, which may cause defects of the same

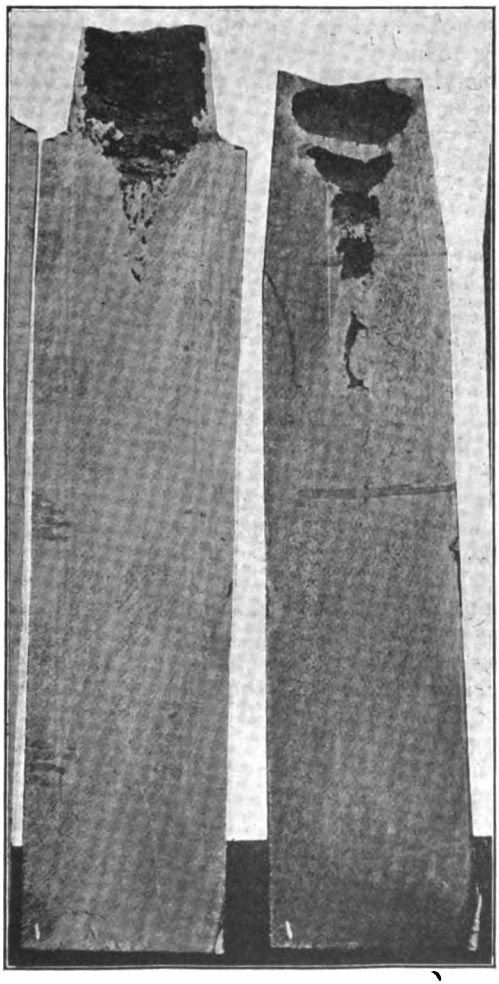

FIG. 3—SPLIT INGOTS. THE ONE AT THE LEFT WAS CAST WITH A SINKHEAD

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nature as a seam. The method of chipping should always be carefully checked up on this account.

Samples for analysis are taken from the various blooms of each heat and analyzed by the laboratory as an additional check on the uniformity of the heat, as well as to insure that there were no mix-ups in heats by the mill. The heat number is stamped on each bloom at the hot shears so that they can be identified at any time in the billet yard or on the chipping beds. This also prevents the chance of a mix-up occurring during charging in the reheating furnace. The blooms of approximately 9-in. square section after chipping, are broken down to billets 2 to 4 in. square, which are again inspected, chipped if necessary and then reheated in continuous furnaces for rolling into finished sizes.

Heat-Treatment and Inspection

The heat-treatment of alloy steels actually commences with the ingot after casting. If the mold is stripped too soon after casting and the ingot heated and rolled too soon, there is danger of obtaining what is termed a green ingot and the finished product from such an ingot is not what it should be. A sufficient interval between casting and charging an ingot in the soaking pits should be allowed to be sure that the interior metal has solidified. Alloy-steel ingots containing fairly high percentages of hardening elements, if allowed to cool in the air to atmospheric temperature, invariably develop shrinkage cracks which may produce defects in blooms at times so bad that it may not be worth while attempting to chip them out, it being more economical to scrap such product. Certain alloy-steel blooms containing high percentages of hardening elements are annealed immediately after rolling, as a safeguard against the serious strains that would be set up, leading to cracks, if the blooms were permitted to cool rapidly in the air from the rolling temperature. The finished bars of sensitive composition are carefully handled after rolling, to prevent cooling strains, and are not spaced on the hot beds but placed against each other to retard cooling. The finished bars of over, say, 0.25 to 0.30 per cent carbon, are carefully annealed, the annealing temperature depending upon the composition, and after a thorough soaking at the proper temperature, are cooled slowly in the furnace and afterward put through roller straightening machines when they are ready for inspection.

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The majority of steel bars of under 0.25 per cent carbon for the automobile industry are cold-drawn, or rough-turned, for automatic-machine work. Before cold-drawing the bars are pickled and then inspected for seams. Most of this grade is used for case-hardening. These lower carbon steels are generally not annealed, on account of the tendency to become too soft for easy machining qualities. Steels which are dead-soft from composition should not be annealed and cold-drawing hardens them sufficiently to impart good cutting qualities.

Inspection is a most important factor and the inspection-department head should not report to or be any part of the mill organization. He should report to the general superintendent or manager, and his decision must be final. The attitude of the works inspector should be that of the consumer and it is beneficial to both the manufacturer and the consumer to have unsatisfactory steel rejected at the works of the former. This not only saves freight, cost of handling and reputation, but when the steel is rejected at the mill it is brought to the attention of the entire mill organization and makes a stronger impression on them, giving the mill superintendent opportunity to discover faults in manufacture in time to prevent a re-occurrence, whereas, if the steel is rejected by the consumer, the first information received by the mill superintendent is by letter, which does not make the same impression upon either him or his organization, and when the steel is finally returned months later it is rusted, or the matter forgotten, and the mill does not have the same opportunity to examine it. When steel is rejected before shipment by the works inspector, remedies can be applied at once rather than months later, during which period much unsatisfactory steel may be shipped before the manufacturer knows of the unsatisfactory product. There is no use concealing the fact that an inspector under the management of the mill superintendent will be more lenient and inclined to try to please his superior by taking chances on material which may not be up to par. Such chances are not taken when the inspection department is separate from the mill organization, and therefore the manufacturer and consumer are mutually benefited.

It is of considerable advantage to both the works inspector and the consumer if the former has opportunity to become acquainted with the details of manufacture of the consumer of the steel. He should have information, for example, as to machining tolerances, the number of

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parts to be machined from the bar, whether the finished part is to be solid or hollow, whether the consumer intends to heat-treat the part and how, or contemplates an upsetting operation, and any other such data. No steel manufacturer obtains 100 per cent good product, and information along the lines indicated will enable the inspector to work more intelligently. The inspector may reject material for very shallow surface seams in bar stock on which the consumer has sufficient machining tolerances to clean up such defects. The point I wish to bring out is that in our country we waste too much good material and every effort should be made to reduce this waste to a minimum, whether it be steel or any other commodity. The manufacturer desires the information mentioned not to see how much bad steel he can ship, but with the idea of reducing unnecessary waste.

Improperly heat-treated alloy steels are inferior to properly heat-treated simple steels. The critical points of two different heats of steel of identically the same composition may vary as much as 30 deg. fahr. This can no doubt be attributed to the usual variation in either the finishing temperature or the rate of cooling from the finishing temperature. I have no data as to whether such variations in critical points are found in heats of steel of the same composition after normalizing; it is possible that after such a treatment they will be more nearly uniform. Therefore, different heats of steel, if treated in the condition in which they are shipped from the mill, not normalized, furnished under the same chemical requirements, will not respond to one standard heat-treatment, and it is therefore good practice for the consumer to determine the proper heat-treatment for each heat of steel he receives. Although the determination of the critical point of each heat is of value, the quenching temperature will increase with the increase in the size of the part to be treated. A very good commercial method for determining the ideal quenching temperature of a heat of steel is to take a number of short bars from it, nick them, and subject them to various quenching temperatures, beginning slightly below the critical point and quenching to 100 deg. or more above it, increasing each quenching temperature by about 25-deg. increments. The bars should then be cold-fractured and the quenching temperature of the bar having the finest-grained fracture should be used as the temperature at which the bars from the heat should be quenched. This temperature will, of

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course, vary somewhat with the size of the section to be treated. Once the ideal quenching temperature is determined, the drawing or annealing temperature can be arrived at, depending upon the required hardness of the part. An absolutely uniform product can be obtained if such a practice is followed. In the case of the common grades of steel it is not necessary to work to such close ranges in the quenching temperature, but to obtain the maximum efficiency with the higher grades of special alloy steels for the more important parts, they should be given the best heat-treatment possible.

To illustrate the effect of variations in the quenching temperature, I selected nine bars of 0.45 per cent carbon simple steel and heated them to temperatures ranging from 1300 to 1800 deg. fahr. and quenched them in water. These bars were all annealed at a uniform temperature of 1175 deg. fahr. This grade of steel contains sufficient ferrite to permit a clear interpretation from its microstructure of the effect of varying quenching temperatures. Fig. 4 shows the average microstructure of these bars after the various quenching temperatures. It will be noted that the most nearly ideal structure was obtained in the bar quenched at 1500 deg. The bars quenched below this temperature did not retain all of the pearlite and ferrite in solid solution. The bars quenched at from 1550 to 1800 deg. are seen from their microstructures to have been quenched at excessive temperature. Therefore, with this grade of steel 1500 deg. is the best temperature at which to quench. The ideal quenching temperature can be readily detected upon cold-fracture, but as it is difficult to reproduce such fractures photographically, I selected the microphotographs to demonstrate the point.

Some years ago I was connected with a manufacturing company which had returned to it about 5000 important parts a year, parts which were the backbone of its product, due to their having failed in service on account of being too hard or too soft. The company bought steel within a 10-point carbon range, forged it into the parts and gave them all practically the same quenching and drawing temperature. Therefore, those which were on the low side of the carbon and manganese limits were too soft and those on the high side too hard. It then established the practice of forging four test-pieces 20 in. long and 2 in. in diameter from each heat received, giving some of these a standard heat-treatment by quenching

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in oil at about 1500 and annealing at about 1200 deg. fahr. Tensile tests were made with these bars and if the results showed that they were either too hard or too soft, the remaining pieces were heat-treated and the annealing temperature regulated accordingly. The correct annealing temperature was always ascertained in the second treatment. The parts then went through the forging and heat-treatment departments by heats which were identified by lot numbers, receiving the heat-treatment determined by the preliminary test-bars. After this practice was put into operation the firm did not have 100 failures per year.

As it is impossible for the steel manufacturer to duplicate a heat of steel of identically the same composition throughout, it is necessary that he be given certain ranges in carbon, manganese, nickel, chromium and the other elements. There are times when one or more of these elements are outside of the allowable ranges and in such cases it should be determined in the event that one hardening element, carbon, for example, is on or below the low limit, whether one or more of the elements, manganese, nickel, chromium or vanadium are on or above the upper limit, as many times it is possible that there are enough hardening elements on the high side to make up the deficiency of the element or elements on the low side, and such a heat will be just as suitable as if all the elements were within specified limits. The effect of the counterbalancing of the various elements in a heat of steel should always be taken into consideration. The important point to consider is whether the desired physical and service properties be obtained from the heat, not whether the heat comes within chemical requirements in every respect.

The essential thing in connection with automobile steels is their heat-treatment, and I wish to emphasize the fact that all the various parts produced from a given heat of steel should receive the treatment that is found to be best for that particular heat. The quenching bath must be near the heating furnace so that the temperature will not be reduced in transit between the furnace and the bath.

Causes of Failure in Service

The metallurgical defects which may cause failures are pipe and deep seams. Their cause can be readily deter-

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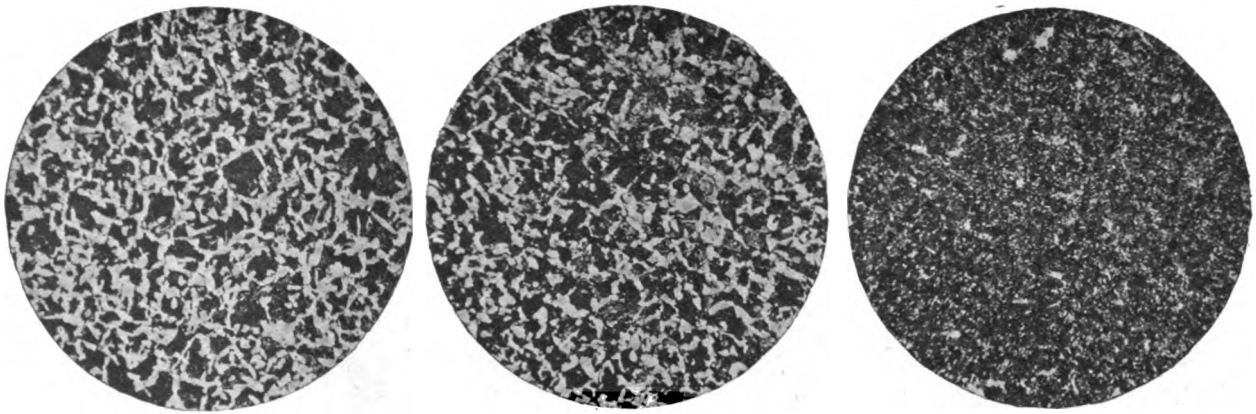

FIG. 4—MICROSTRUCTURE OF 0.45 PER CENT CARBON STEEL BARS

The temperatures in degrees fahrenheit to which the various bars were heated prior to quenching are indicated below

1300 1350 1400

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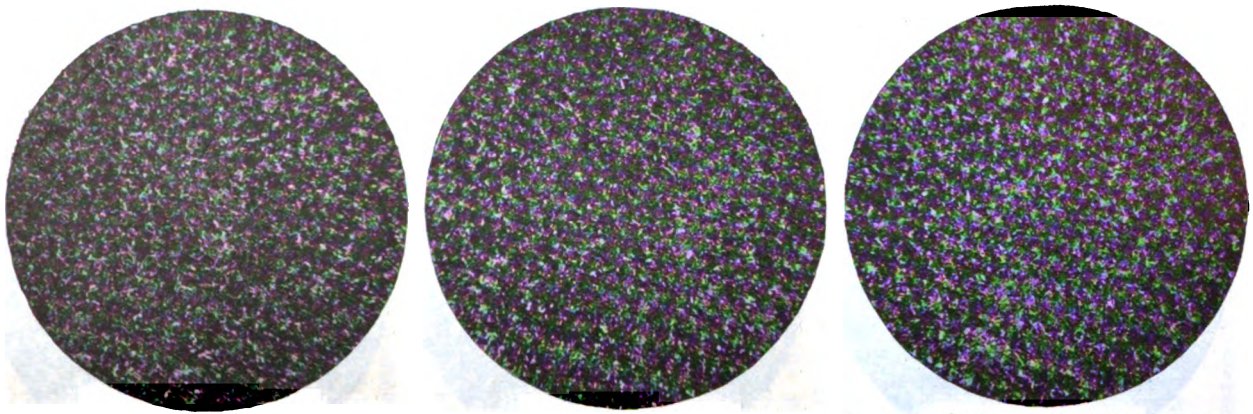

The temperatures in degrees fahrenheit to which the various bars were heated prior to quenching are indicated below

1450 1500 1550

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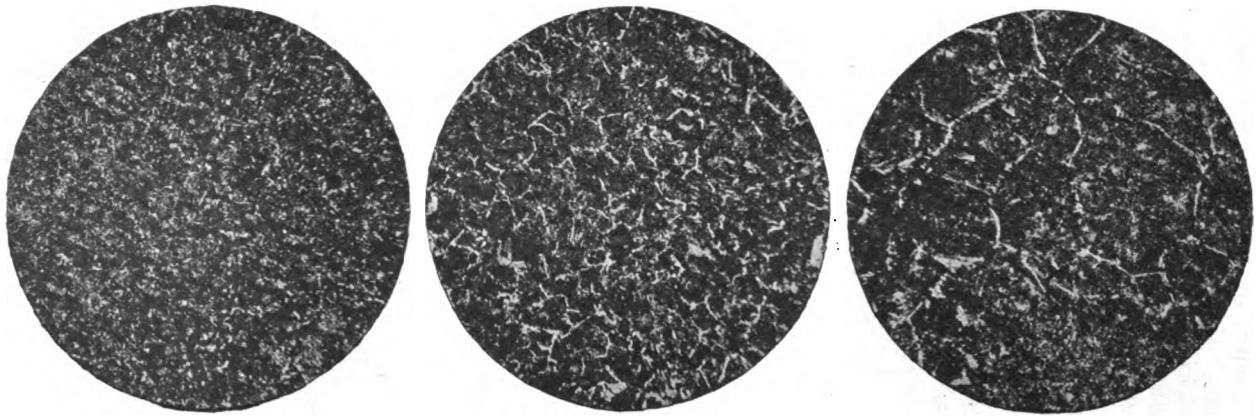

The temperatures in degrees fahrenheit to which the various bars were heated prior to quenching are indicated below

1600 1700 1800

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FIG. 6—MANNER OF PILING AND MARKING BILLETS TO PREVENT MIXING THE VARIOUS GRADES OF STEEL

are darkened. The silvery luster is doubtless acquired by the opposite surfaces hammering each other. The progressive development is shown by the concentric ripples on their silvery faces. The walls of an incipient fissure are separated a very minute distance, probably represented by the elastic resilience of the steel in that vicinity. The phenomenon of permanent set or permanent elongation of the steel cannot take place when a fissure is formed in a matrix of structurally sound metal. Seamy or spongy steel would appear to favor interior flow of limited degree without fracture.

Factors Determining Sources of Supply

The points to consider in deciding upon the source of steel to be purchased are

(1) Is the steel manufacturer in a position to obtain raw material of good quality
(2) What are the manufacturer's facilities for testing and inspecting his product
(3) Has he adequate chemical and physical laboratory equipment and an efficient organization in these departments

A prospective purchaser of large tonnages of high-grade steels should personally inspect the plant of the manufacturer and become acquainted with the manufacturer's organization. In this way he can generally form his own opinion as to the ability of the manufacturer to furnish him with the desired product.

Is the plant of the manufacturer clean? In a clean and orderly plant, steel is properly marked, piled and assorted, and the workmen are more efficient. If a plant is dirty, workmen become careless and mix-ups occur. Fig. 6 shows the manner in which billets should be piled and properly marked to keep the various grades of steel from becoming mixed.

The past performance of the manufacturer should be taken into consideration; in other words, what grades of material has he been accustomed to manufacture. The experimenter should be given an opportunity to demonstrate his ability to manufacture special steels, but the consumer should avoid ordering too large a tonnage from him until he has demonstrated what he can do.

Each automobile manufacturer should have in his organization a competent metallurgical engineer who is conversant with the mechanical design of the various

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parts and has a knowledge of the strains and stresses to which they are subjected in service. He should have full authority to decide upon the type of steel to be used and the heat-treatment necessary to impart the best combination of physical and service properties. Such an engineer can save a company thousands of dollars by reducing service failures. For parts subjected to steady low strains the automobile engineer will select one of the cheaper grades of steel of a composition that will have the necessary tensile strength, elastic limit, elongation, etc., to withstand these strains. For parts subject in service to severe vibration and shocks he will select a high-grade alloy steel and pay particular attention to obtaining the very best properties possible from this steel by correct and careful heat-treatment.

There is one important commercial point that I think should be emphasized. The consumer in making his alloy-steel connections should, after determining upon proper sources of supply, retain these and not allow minor price fluctuations to affect him. Too often purchasers magnify the importance of saving a fraction of a cent per pound and contract with new sources of supply, which, however capable of making good steel, due to lack of knowledge of the individual plant's requirements, often cause increased shop and service losses which overbalance by far the price benefit.

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METROPOLITAN SECTION PAPER

DIRECT MULTIPLE-SPEED AUTOMOBILE REAR-AXLE DRIVES

By H C McBrair[1]

The first car credited by the author as being equipped with two or more direct drives is the Sizaire-Naudin, in 1905. The transmissions of this car and of one embodying similar principles of gearing, brought out in 1909, are described and illustrated by diagrams. After the Sizaire-Naudin, the next double direct-drive transmission was the Pleukharp transmission axle, made in 1906, although the real ancestor of the present double-drive rear axles is the 1906 Pilain transmission; both are described and illustrated. Other early American and foreign forms are commented upon and diagrammed, including the Austin design, believed by the author to be the first to use a two-speed axle of the simplest and lightest possible type to provide two direct drives in connection with a separate gearset to give additional forward speeds and the reverse.

Modern two-speed axles are reviewed, with critical comment and diagrams, and considerable discussion of gear ratios is included. Following this the author exhibits and describes several so-called practical axles, a light two-speed axle weighing not more than the average ordinary axle in common use, a two-speed and reverse axle with splined differential housing upon which the gears slide and a three-speed forward and reverse axle, the last being shown connected to the chassis and as used in connection with an internal-gear drive for truck purposes. Regarding the relation of gear ratio to horsepower, the author quotes J. G. Vincent and E. T. Birdsall to the effect that an indirect gear ratio below the direct, that is higher than 60 per cent of the direct, will give very little added ability. An assembly for high speed is illustrated and described, followed by diagrams of gear assemblies, a special ball bearing and a carrier bearing.

I believe that the first car equipped with two or more direct drives and sold to any considerable extent was the

[1]Middletown, N. Y.

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Sizaire-Naudin, first exhibited at the Paris Small Inventors' Show in 1905 and actually placed upon the market a few years later. The transmission of this car (See Fig. 1) is located on the rear axle and consists of a single large crown gear mounted on the differential, just as the larger gear is usually mounted in the ordinary bevel-gear-drive axle. Three pinions of different diameter are provided to mesh with this crown gear for three forward speeds, in addition to the reverse idler. This gives direct drive on all three forward speeds, but it is effected at the expense of an abnormally large diameter of crown gear, which has teeth of a curved form giving point contact only with the pinions and a complicated motion of the pinion shaft in two directions for gear-changing.

A transmission embodying similar principles of gearing, worked out in a different manner, was brought out

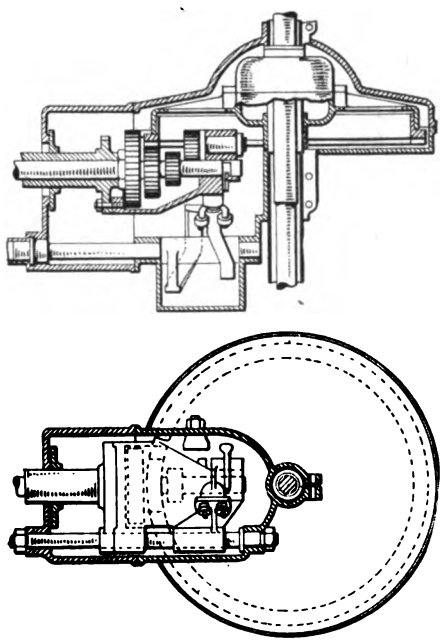

FIG. 1—SIZAIRE-NAUDIN TRANSMISSION

in 1909 by the Seagrave Co., Columbus, Ohio, but I am not aware that it ever met with any commercial success. In this device, which was called the Probst or Stone-

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Probst axle (See Fig. 2) there were only two direct drives, the low and reverse gears being geared down so that the size of crown gear required was not so great for the same power capacity; and a single pinion was used, sliding along its shaft without motion in any other direction, to obtain the several changes of gear ratio. This was accomplished by cutting two sets of crown teeth on the same face of the axle gear, with space between the two circles for a neutral position of the pinion. These

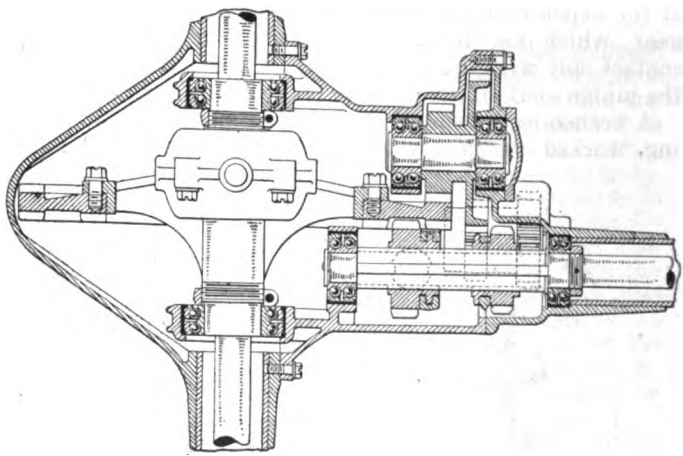

FIG. 2—STONE-PROBST AXLE

two crown gears gave direct drive on the two higher speeds. A third set of crown teeth was cut on the back of the same blank, into which a countershaft pinion constantly meshed. A gear for first speed also was on this shaft and was engaged by shifting the sliding pinion forward from its neutral position, which was just in front of the rim of the crown gear. An idler was slid into mesh with a countershaft gear and the sliding pinion to obtain the reverse.

EARLY AMERICAN AND FOREIGN FORMS

After the Sizaire-Naudin the next real double direct-drive transmission to be exploited was the Pleukharp transmission axle, made in 1906 by the Direct Drive Axle Co., Columbus, Ohio. The principle of this gear is shown in Fig. 3. There are two bevel pinions and three bevel gears, all being mounted loosely on their shafts. There are also two double-jaw clutches and a roller-coaster

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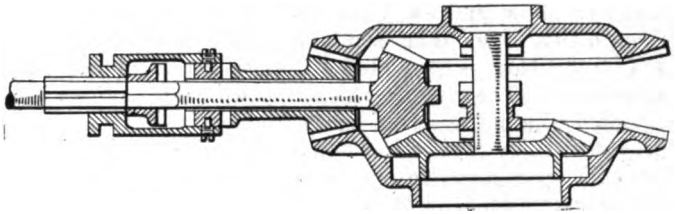

FIG. 3—PLEUKHARP TRANSMISSION AXLE

clutch of the type which has now come into use in connection with engine starters. The diagram shows the low-gear position, the drive being through the roller clutch. The reverse is obtained by shifting the clutch on the axle so as to engage the other large gear, the clutch on the propeller-shaft being still in the rear position, where it engages the forward pinion. For high gear, both clutches are shifted from reverse position and the roller clutch allows all the gears which are not in use to stand idle. Only two forward speeds are provided, the clutch on the propeller-shaft selecting between them, while the clutch on the axle is not disturbed except when the reverse is brought into action.

What may be considered the real ancestor of the present double-drive rear axles is the Pilain transmission (See Fig. 4), which was exhibited at the Automobile Club of

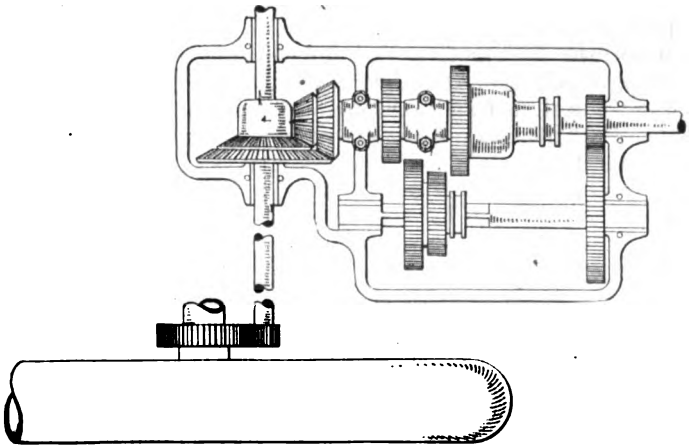

FIG. 4—PILAIN TRANSMISSION

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America show in New York City in December, 1906, although this is not truly a double direct-drive, as a second gear reduction is provided by spur gears at the rear-wheel hubs. The way in which the two bevel pinions were engaged was not revealed by the makers at that time, but probably there was something in the way of a pair of internal spur-gear clutches inside the small housing on the primary gear-shaft.

Designs similar to the Pilain have been used in gear-boxes made integrally with jackshafts for double-chain

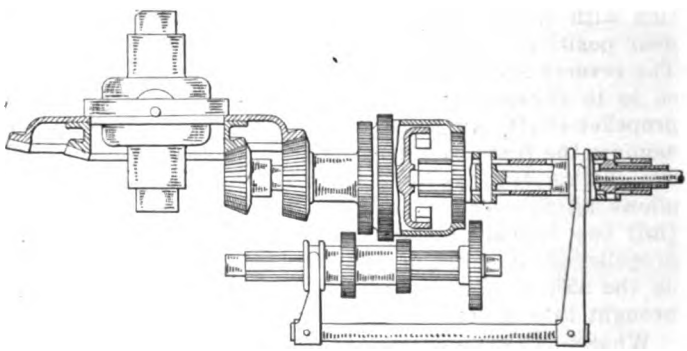

FIG. 5—LANCIA TRANSMISSION

drives in a number of makes of car, notably the Italian Lancia, shown in Fig. 5, and the French Berliet, Fig. 6, made familiar by its production in this country by the American Locomotive Co. for several years before it brought out the Alco car; and in a truck transmission, Fig. 7, designed and exhibited by the Merchant & Evans Co., Philadelphia. The last named firm designed also a similar rear-axle-mounted gearset, which was not to my knowledge built and sold, although the truck transmission has been sold in some quantity.

A form of transmission which was first used in the Mors car some ten years ago, has two pairs of bevel gears, one for the direct drive and the other for the countershaft. While this gives direct drive on only one gear, it reduces the number of gears through which the power is transmitted on the lower gears. This type of transmission was made familiar in this country on chain-driven cars by its use on the Knox, Matheson and Chadwick cars. The American designs favored placing the bevel gears back-to-back, bringing the countershaft to the

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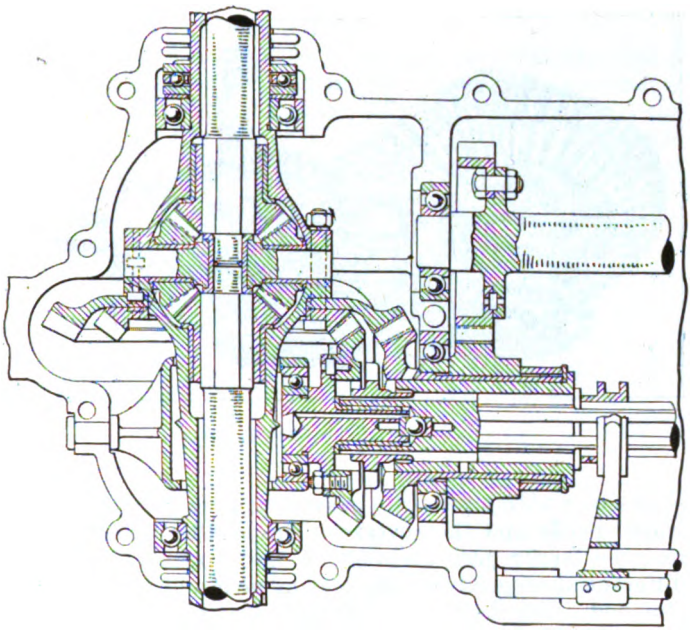

FIG. 6—BERLIET TRANSMISSION

other side of the transmission, and one of these gears at least was of the selective type.

I believe that the Austin Automobile Co., Grand Rapids, Mich., was the first to use a two-speed axle of the simplest and lightest possible form to give two direct drives in

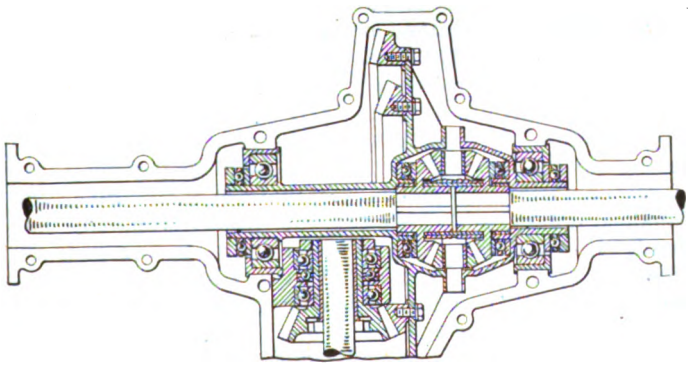

FIG. 7—MERCHANT & EVANS TRANSMISSION

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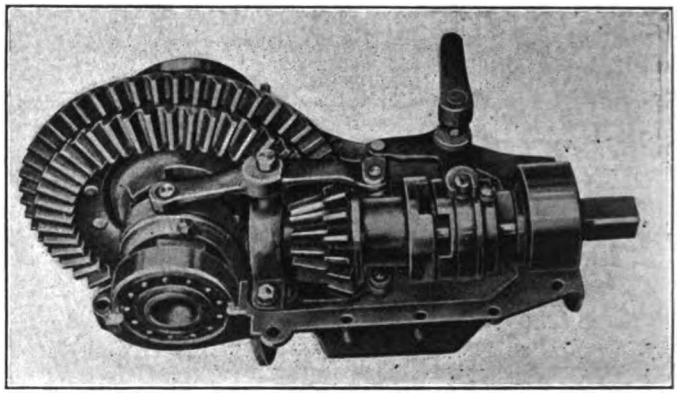

FIG. 8—AUSTIN TWO-SPEED AXLE

connection with a separate gearset to give additional forward speeds and the reverse. The smaller bevel pinion and the larger gear are fast on the propeller-shaft and differential respectively, the mating gear and pinion being clutched. The two jaw clutches required are interconnected so as to operate like one double clutch, while the construction is simpler and more substantial than that of any of the double clutches used in preceding constructions of this sort.

This axle gives two independent direct drives and in conjunction with a three-speed gearbox, six properly graded speeds. The chief advantage, of course, is the double direct-drive. The construction is very clearly shown in Fig. 8. There are two bevel pinions and two bevel gears, the pinions being concentric and mounted one closely behind the other, and the gears are the same. The larger bevel pinion and the smaller bevel gear are loose upon their shafts, but can be secured thereon by dog clutches. The shifting collars of these clutches are interconnected so that when one is in engagement the other one is free. The largest pair of gears gives the smallest gear ratio. So far the Austin company has made three different sets of these gears, giving gear reductions of 3½ to 1 and 2 to 1; 4 to 1 and 2½ to 1; 4½ to 1 and 3 to 1. This Austin design overcomes certain of the difficulties by the use of one clutch on a pinion and the other on a gear, at the same time gaining a very compact construction. As the outer gear is solid on the

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differential, the inner one is just as well backed-up when clutched as though it were solid also.

For further suggestions of double bevel construction a drawing of the bevel gears of the Berliet design is shown in Fig. 6. This was used in the gearbox of the Alco car as long as a double-chain drive was used on that car. Here we find the shifter sleeve passing through the bore

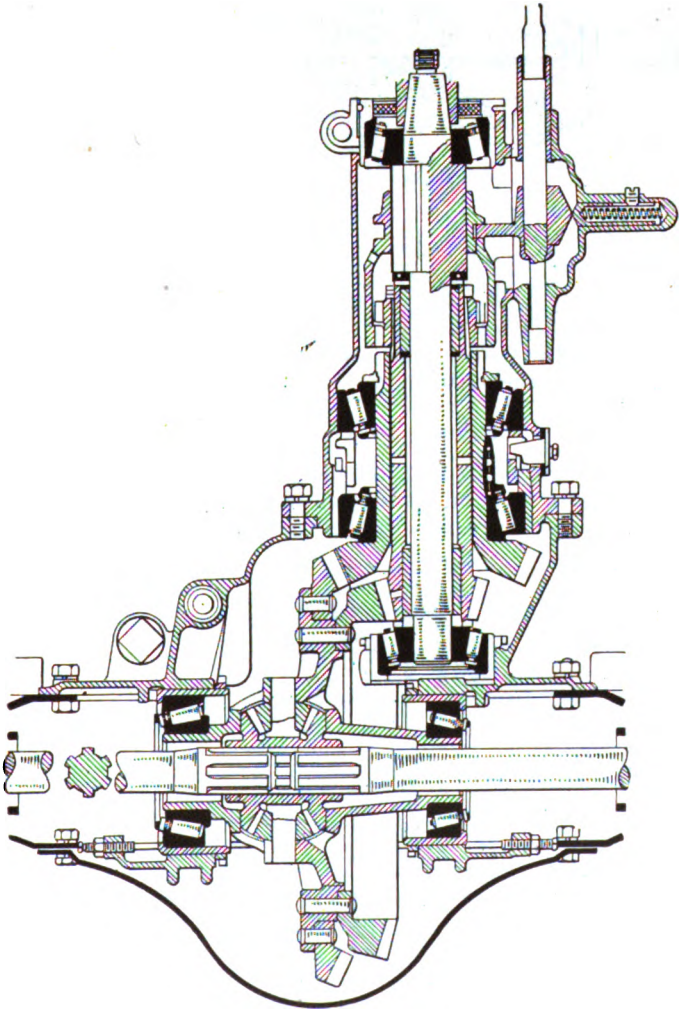

FIG. 9—CADILLAC TRANSMISSION

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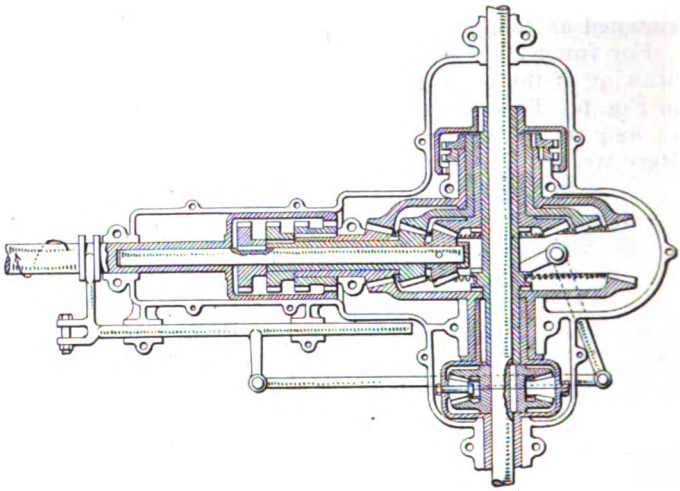

FIG. 10—MUREN AXLE

of one of the bevel pinions, the jaw clutch being between the pinions themselves.

MODERN TWO-SPEED AXLES

Fig. 9 shows that in the bevel pinion and jaw-clutch assembly of the Cadillac design every force has been considered, and there is no uncertainty as to sufficient sup-

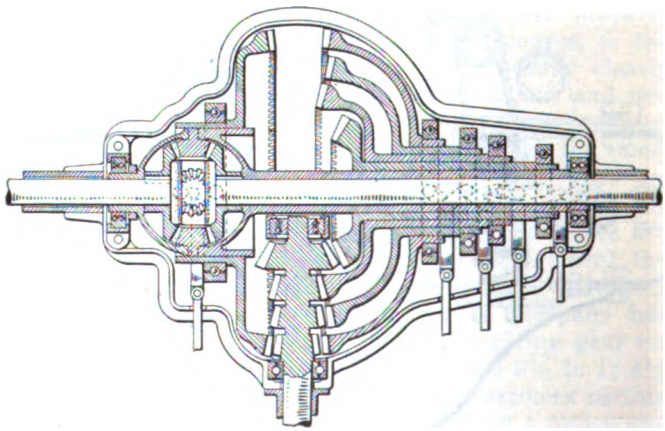

FIG. 11—TRANSMISSION GIVING FOUR FORWARD SPEEDS AND ONE REVERSE

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port such as we observe in the Pleukharp design. Yet we apparently see a few leaves out of the Pleukharp book in the separate support of the outer sleeve with its bevel pinion. The universal-joint is attached to a solid shaft which goes through to a bearing back of the bevel pinions as though there were but one pinion. However, neither

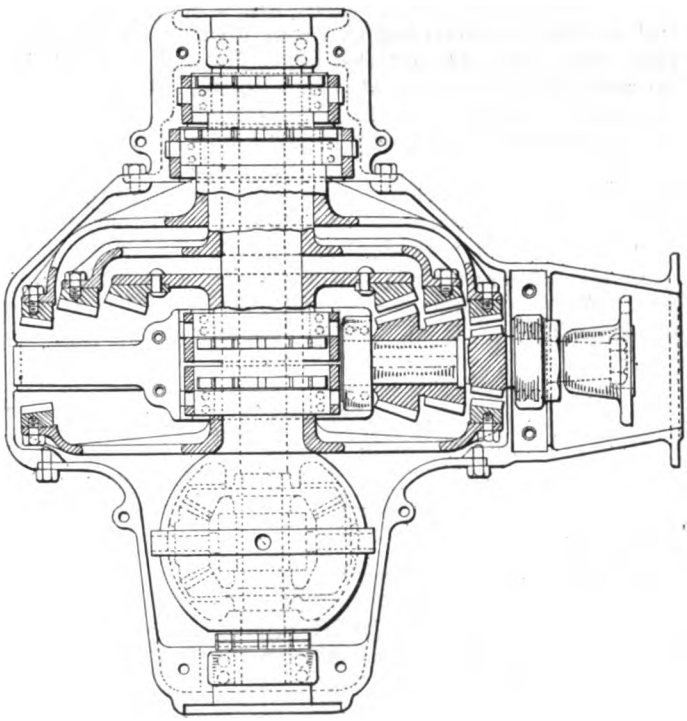

FIG. 12—A LIGHT TWO-SPEED AXLE

pinion is keyed to this shaft. The smaller pinion with the sleeve is supported on the shaft by two small roller bearings and located by ball thrust-bearings. If these look small as compared with other bearings in the construction, it must be remembered that they are idle whenever the small pinion is driving and turn only when the pinion is running idle. The larger pinion, with its sleeve, is supported directly from the housing by two taper roller bearings, there being clearance between the two sleeves and

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no chance for contact or wear. One of the advantages gained by this is that the mesh of the larger pinion can be adjusted by the two outer bearings and the mesh of the smaller pinion can be independently adjusted by the two bearings which support the shaft. The forward end of each of these sleeves carries a spur gear which is used as a clutch, connection being made with the propeller-shaft through the internal gear, which is shown in neutral position between the two spur gears. The internal gear slides upon an enlarged and splined portion of the through-shaft, being operated by a shifter. A spring lock retains the shifter in position for clutching either gear, but the neutral position, in which the clutch is here shown for the sake of clearness, is not used. The two large bevel gears are solidly attached to the differential, and the sizes are such as to give a ratio of 3.66 to 1 with the smaller pair, and 2½ to 1 with the larger pair.

As the bevel-gear ratios of the Cadillac are 2.50 to 1 and 3.66 to 1, while the second gear-reduction in the transmission is 2.18 to 1 they give gear reductions as

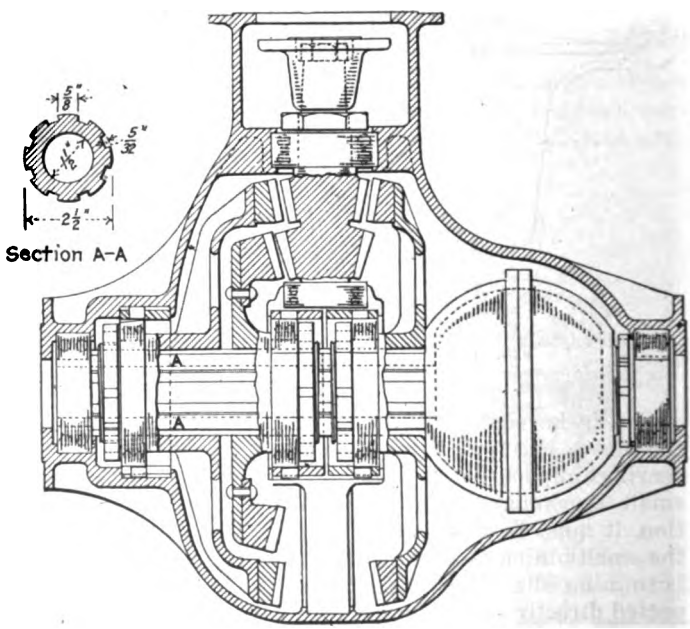

FIG. 13—A TWO-SPEED AND REVERSE AXLE

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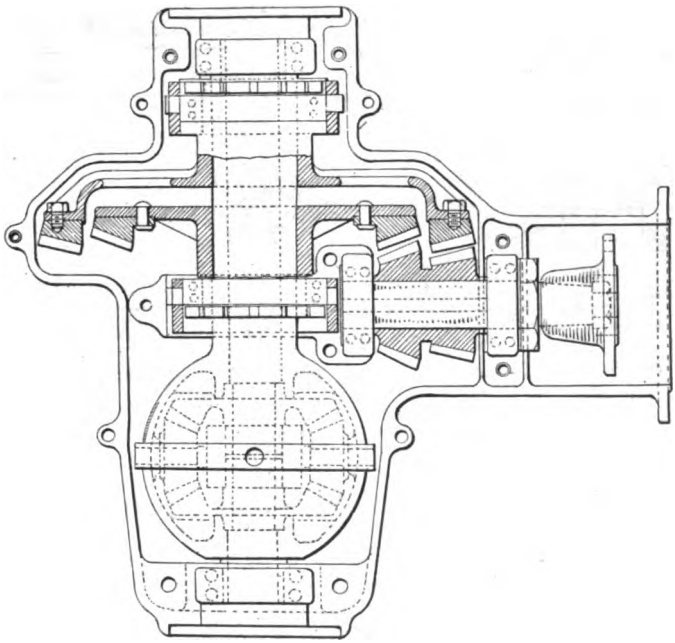

FIG. 14—A THREE-SPEED FORWARD AND REVERSE AXLE

follows for the four highest gear ratios: 2.50 to 1, 3.66 to 1, 5.41 to 1 and 7.98 to 1. These are in almost exact geometrical ratio, the multiplier being 1.47, which is the ratio between the two direct drives; as 8 to 1 is low enough for everything except emergencies and extreme grades, it is necessary to have a lower gear for only such conditions. The same multiplier used again gives a low-gear ratio of 11¾ to 1, which is near the actual ratio of the lowest gear obtainable, making five gears in nearly geometrical ratio from 11¾ to 1 to 2½ to 1. The arrangement as adopted has the practical advantage that the car can be started on either of the rear-axle drives, using the regular transmission gear-reductions as though there was no double direct-drive. This would still be true if the low gear in the transmission were in geometrical relation to the other gears in the transmission, but this would give a uselessly low gear of 17.3 to 1. On the other hand, it would bring the two direct drives too closely together, and make it necessary to resort to an indirect

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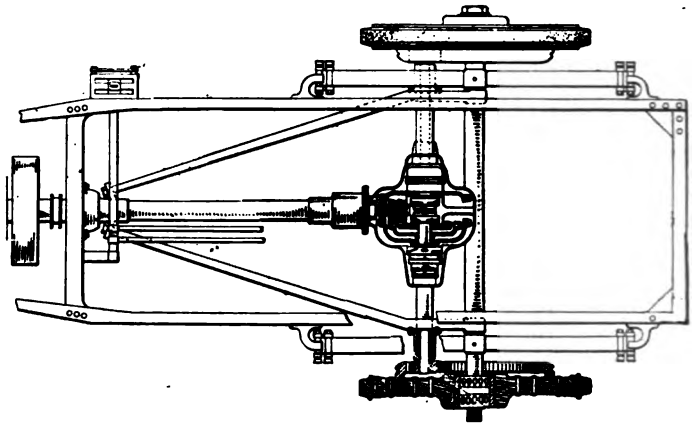

FIG. 15—A THREE-SPEED FORWARD AND REVERSE AXLE CONNECTED TO THE CHASSIS

drive more often if the multiplier in the geometric ratio were reduced to 1.35 so as to give six speeds in geometrical progression from 2.5 to 1 to 11.6 to 1. It would be hard to improve upon the ratios that have been adopted. The Muren axle, Fig. 10, has three speeds forward and a reverse. In this axle dog clutches are used on both pinion gears and bevels. The use of hollow pinion-shafts limits the gear reduction and places the high gear on the

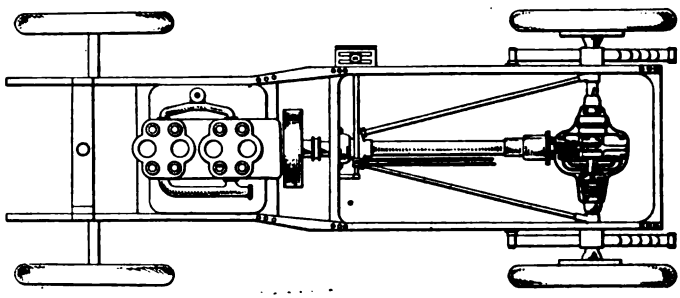

FIG. 16—A THREE-SPEED FORWARD AND REVERSE AXLE EMPLOYED IN CONNECTION WITH AN INTERNAL BEVEL-GEAR DRIVE ON MOTOR TRUCKS

large bevel. The idling of gears without proper bearings is another bad feature of this axle.

Fig. 11 shows a four-speed forward and one reverse device with a 2 to 1 ratio on high and a 9½ to 1 ratio on low. This axle with 36-in. wheels gave more ground

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clearance than one of the popular makes of car of today; more than 9 in. clearance. The objection to the axle was its weight; it also had a poor shifting device.

We now come to practical axles. The first one, Fig. 12, is a light two-speed axle weighing not more than the

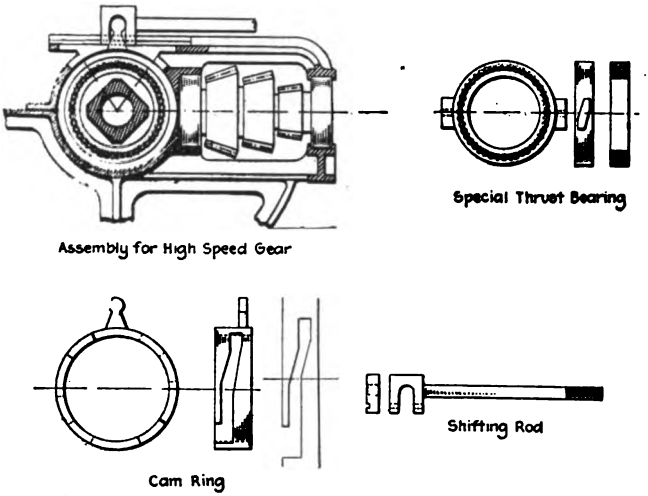

FIG. 17—DETAILS OF A TRANSMISSION IN WHICH THE GEAR SPIDERS SLIDE ON A SPLINED DIFFERENTIAL HOUSING

average ordinary axle in common use. The clearance on this axle is 10½ in. with 34-in. tires. Quoting J. G. Perrin, "The effect of unsprung weight is a broad subject. I think that there is a happy medium between sprung and unsprung weight; if we go to either extreme we lose in the best riding qualities of the car." J. N. Heald says, "I have been driving lately a car with a two-speed axle

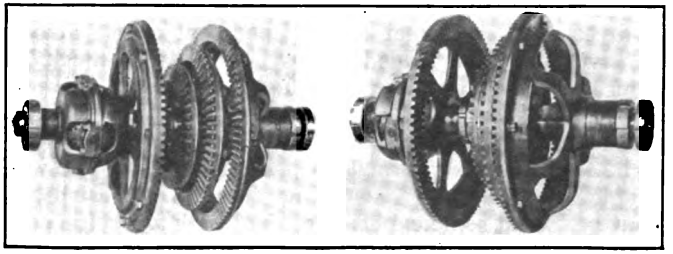

FIG. 18—TWO TRANSMISSION GEAR ASSEMBLIES

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having ratios of 2½ to 1 and 3 2/3 to 1. I use the 2½ to 1 ratio very much; and yet in driving an hour I will change perhaps ten times from one speed to another. It is interesting to show the difference between the engine running first on one bevel gear and then on the other. At a speed of 25 m.p.h., for example, a change from the 2½ to 1 gear to the low bevel will tend to retard the car unless additional gas is given the engine to increase its speed quickly by about 50 per cent. The additional gas required and the vibration of the engine at the higher speed seem to indicate quickly and conclusively the value of two speeds in the rear axle. It seems that the throttle does not need to be as wide open in traveling on level ground with the 2½ to 1 gear as on the low bevel, to produce the same car speed, showing that a certain amount of gas is required to turn the engine over at the higher speed, which produces no actual propelling effect as far as the car is concerned. I have been wondering lately whether a six-cylinder engine developing the same power as the four-cylinder in this car in connection with a two-speed rear axle, would not prove to be the ideal car."

Fig. 13 shows a two-speed and reverse axle; with splined differential housing upon which the gears slide. This axle will give ample reduction on low gear and more than 9-in. ground clearance. Fig. 14 illustrates a three-speed forward and reverse axle; Fig. 15 the axle as connected to the chassis, and Fig. 16 the axle used in connection with an internal-gear drive for truck purposes. The gear ratios that are easily obtainable with this axle are from 2 to 5 for high, from 3 to 6 for second and from 6 to 12 for low.

The Relation of Gear Ratio to Horsepower

J. G. Vincent has said: "An indirect gear ratio below the direct, that is higher than 60 per cent of the direct, will give very little added ability. If it is as much as 70 per cent of the direct, it will not give any. I will put it another way. Take a hill of certain grade that a given car will just climb on the high and maintain 20 m.p.h. Make the gear ratio 60 per cent and the car will be able to accelerate." Quoting from E. T. Birdsall, "That bears out some experience I had with a foreign car. It had three speeds. The second speed was 66 per cent of the third. On a given grade it would not pick up,

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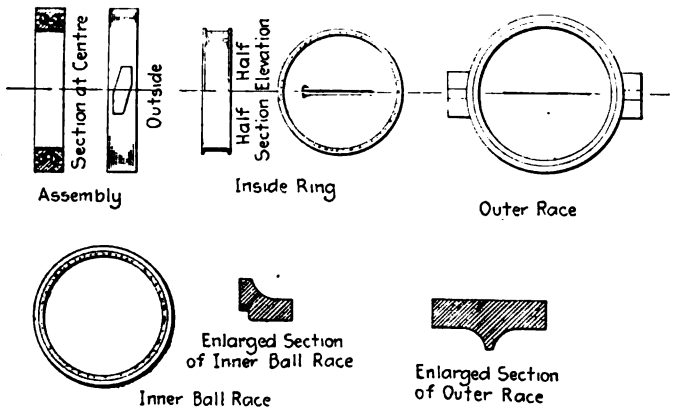

FIG. 19—A SPECIAL BALL BEARING FOR TRANSMISSIONS

whereas with cars that I made with the second speed 60 per cent of the direct there was no trouble in accelerating. I found practically the same thing that Mr. Vincent found, that 60 per cent of the high gear is about as high as one can go to advantage."

The gear spiders shown in Fig. 17 slide on a splined differential housing, being moved into position and locked by rotating a cam ring against the lugs on the ball bearing. The ball bearing is fastened to the gear spiders in the usual manner; the cam ring has a recessed bearing

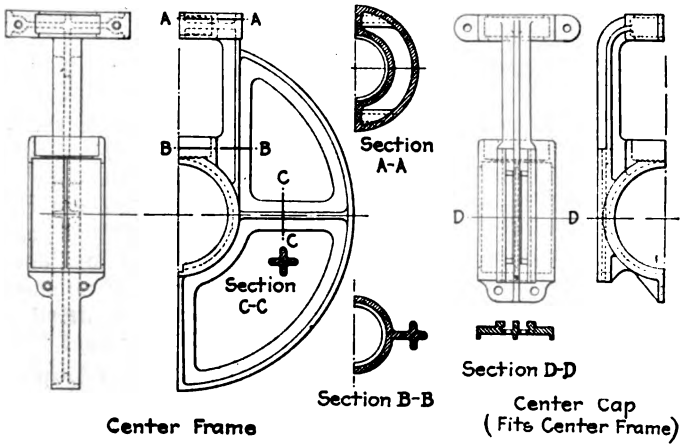

FIG. 20—A CARRIER BEARING

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so that it cannot move horizontally. As the cam ring is rotated to put a gear into mesh, the lug passes along the inclined plane until the flat surface is reached and the gear becomes locked in position; when the lug is at the center point the gear is in neutral. When one gear, the high gear, for instance, is in mesh and the lug is at the flat-surface end of the inclined plane, the cam ring on the second-speed gear has passed from the center point to the long flat surface and has become locked out of mesh at that point. The gears are coupled up in the usual manner. It is possible to have a three-speed forward and reverse drive, using a light two-speed axle for high and intermediate speeds and a light gear-box for low and reverse. This can be made so as to use only one lever.

The low-speed ratio drives are through spiral bevel gears. A low-speed pinion with nine teeth would give excellent results, since it would probably not be used for more than 2 per cent of the total mileage.

Fig. 18 shows two gear assemblies, Fig. 19 a special ball bearing and Fig. 20 a carrier bearing.

THE DISCUSSION

J. A. ANGLADA:—We hear of proposed five and six-speed trucks, with reference particularly to trucks equipped with pneumatic tires. Why are not more two and three-speed rear axles used?

DR. MCBRAIR:—One reason advanced is greater weight, but the two-speed axle is as light as the average standard axle made today.

P. M. HELDT:—The gear efficiency is one necessary consideration. With a double direct-drive the gearset is not used so much. Gear efficiency is not a definite thing but varies with the speed and the load. A well-cut pair of spur or bevel gears will show 98 per cent efficiency if operated at moderate speed and with a fair load, but the efficiency will decrease as the load decreases. A gear running free requires some power to drive it and does no effective work; hence the efficiency is zero. If no more power is taken out of it than that required to drive it free, the efficiency cannot be more than 50 per cent.

A. L. CLAYDEN:—I do not remember who was responsible for the first multiple-speed axle. It was produced long ago. I remember such a car, but it was not the Pilain. Another French car with a three-speed axle was

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produced about 1903, and Renault had at least a two-speed rear axle about 1904 or 1905.

Another form of multiple direct-drive was experimented with in England about 1900. Its pinions consisted of two disks spaced an adequate distance apart and connected by pins parallel to the axles. I believe it showed a high efficiency.

The reason the multiple-speed axle has not been used to a greater extent lies not so much in its weight, because we have realized only in recent years that an ounce in the rear axle is worth about 50 lb. above the spring, as far as easy running is concerned, but is due to the extreme difficulty of shifting gears with accuracy and without interference with that operation due to road shocks. The Cadillac magnetic method of operation was developed to overcome the extreme difficulty of arranging a mechanical shift. I do not mean to suggest that it is impossible to arrange a straight mechanical control, but it is not easy. Many engineers prefer to have someone else work it out for them.

H. W. SLAUSON:—I rode in Dr. McBrair's car six or seven years ago. It was really a revelation in control and general ease of handling. The various speeds, second or third if necessary, could be obtained with the same feeling as though driving on direct all the time.

It is said that the two-speed rear-axle Cadillac was an ideal car to drive for those who understood just how and when to operate it.

MR. CLAYDEN:—I have recently driven an Austin rear axle and the shifting is very good. I think that it is no easier to drive than an ordinary transmission, and it requires no more intelligence.

H. C. GIBSON:—With the McBrair type of axle there is less churning of the oil than with the other types of multiple-speed rear axles. It may happen that he can use light oil, in which case there would be a great increase of efficiency. What is the actual means of shifting?

DR. MCBRAIR:—The first experiments were made using grease in the rear axle, but in cold weather the bearings did not receive proper lubrication. We afterward found that engine oil gave the best results.

In regard to gearshifting, it is possible to shift from high to second, or from second to high speed while running along at 25 to 30, 10 to 15, or 50 to 60 m.p.h. The gear can be shifted at least eighty times per minute if the hand lever can be pulled that fast and I think it can.

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It is possible while running at 25 m.p.h. to kick the clutch out and throw the reverse gear in so that, when the car stops and the clutch is let back in, the car will go backward. It is impossible to "grind" the gears in any way, or to get any noise when shifting from one gear to the other. The gears are as quiet as any in high-gear drive.

MR. ANGLADA:—On the average car there are low-gear reductions of 12 to 16 and 18 to 1. Is it possible to obtain such reduction with a multiple-speed axle without using an excessively large-diameter housing for the gears? I recently saw a five-tooth spiral-bevel pinion that had been in service about 7000 miles and showed no sign of wear. Perhaps small-diameter gears of this type are the solution of the problem of designing multiple-speed bevel-gear rear axles which are not excessively large in diameter.

DR. MCBRAIR:—A man interested in axle manufacture recently told me he had a seven-tooth pinion that had been run several thousand miles. Better than a 12 to 1 ratio can be secured with a small gear and good clearance. If the benefit of the gear ratio of 60 per cent of direct drive, with indirect drive, can be obtained, 12 to 1 ratio is as good as 15 to 1, or more, through the gearbox.

I have been driving a car weighing about 3500 lb., including equipment, and it has always come through. Once, coming over the mountains through deep snow, I had the radiator leaking from bucking snowdrifts. So, I think the gear reduction is a small part of it. We started with a gear ratio of 12 to 1 on low. We have gradually gone down until we have 7½ to 1 for low, 4 1/5 to 1 for second and 2¼ to 1 for high speed.

Referring to car mileage, the car formerly gave 12 miles per gal. when gasoline was good. At that time, on a test run, with the car in good condition, we carried four passengers and drove from Middletown, N. Y., to Albany, N. Y., and return, making 12 miles per gal. Later we made the same run with the same load, using the three-speed axle, and averaged 33 m.p.h., going 65 m.p.h. at times and running slowly through cities. Without the gearbox the gasoline mileage increased to 20 miles per gal.

M. C. HORINE:—One type of multiple direct gearing has escaped our notice. It was a French device employing a worm gear of variable pitch meshed, as I recall, with a roller wheel. This worm slid back and forth and gave variable gear reduction. It was a very simple device, as there were only two gears.

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C. F. SCOTT:—How does Dr. McBrair's axle compare with the ordinary type of gearshift in shifting from high to second speed?

DR. MCBRAIR:—It is equally easy to shift from high to second and from second to high gear; there is absolutely no difference. We speeded to a maximum on high gear, threw into second and let the clutch in. The two passengers in the rear seat immediately proceeded toward the front, but that was all. It is possible to shift at any speed without paying any attention to the clutch; aside from the jar it works all right.

A. M. WOLF:—In the 12 to 1 low-speed set, what is the pitch of the gear teeth?

DR. MCBRAIR:—They are six-pitch teeth; in using a spiral there would be seven teeth. Better than a 12½ to 1 ratio can be obtained with a 15-in. gear, giving over a 9-in. clearance.

MR. WOLF:—With an eight-pitch gear, assuming one could go that low on tooth size, with a twelve-tooth pinion, 34-in. wheels and 13½ to 1 total gear-reduction, there is approximately a 6½-in. ground clearance. With a six-pitch gear the ground clearance would only be about 3⅛ in.

I think that one good point in Dr. McBrair's transmission is the engagement of the teeth by face contact instead of sliding the teeth lengthwise, which accounts for the ease of shifting.

MR. HORINE:—Are not gears that are clashed into mesh subjected to greater shock, with a dragging clutch, than in the sliding mesh where the pressure occurs closer to the root of the teeth instead of having the tips of the teeth take the initial shock? In other words, the shape of the teeth being somewhat rounded, in clashing them into mesh the car must actually be moved slightly forward. Is it as easy or easier to strip gears that clash, in comparison with those that slide into mesh?

DR. MCBRAIR:—That question can best be answered by showing you two of the gears that were on the car that traveled 43,000 miles. Those gears are here. In meshing the gear simply rolls in.

L. G. NILSON:—It is my opinion that it is easier to bring gears together in this way than by the customary sliding method. In sliding gears the first contact is on the corners of the teeth, with the result that the corners are often bruised or broken. If the gears are brought together radially, the strains are distributed along the

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whole length of the teeth. I would like to ask whether in Dr. McBrair's construction any change has been made in the pressure angle, addendum and clearance, so that when the gears are brought together the outer points will not hit too hard? It seems that the teeth should be made more pointed and not as flat as they are shown in the drawings.

W. S. HOWARD:—On bevel-gear transmissions, the Government has been holding us to full load on the reverse for 15 min. Lately, the requirement has been changed to 1 hr. at one-half load. It has been a hard matter to make gears and bearings that would meet this test, even at the reduced horsepower for the longer period.

DR. MCBRAIR:—Regarding the teeth, standard stub teeth would be better. I originally used some gears with long teeth and found they shifted with stub teeth just as well. The same thing holds true with stub teeth on a spiral-bevel gear.

MR. CLAYDEN:—I believe it is necessary and customary in all bevel-gear drives to provide a certain amount of adjustment. It is obvious that if there are more than one pair of bevel gears, individual adjustment is necessary in each successive pair.

DR. MCBRAIR:—Each individual gear is arranged for adjustment. In fact, the adjustment is the same as is used in the ordinary rear axle.

MR. NILSON:—In some of the early French cars, the Renault at least, were not the gears put in or out of mesh by tumbling them radially?

DR. MCBRAIR:—Yes, with a handle near the floor.

MR. HORINE:—In the old Packard car which had a three-speed progressive gearset, the reverse idler gear did not slide but was dropped into mesh. As far as I know this worked well, although it was a double-clash operation.

MR. GIBSON:—It appears to me that the ease of engagement when shifting gears, which is attributed by Dr. McBrair to his design of transmission, can be well understood when we consider that the peripheral speed of gears about to engage is less in the McBrair type than in the sliding type of transmission.

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MID-WEST SECTION PAPERS

SOME FACTORS OF ENGINE PERFORMANCE

By V R Gage[1]

A large number of tests were made in the altitude laboratory of the Bureau of Standards, using aircraft engines. The complete analysis of these tests was conducted under the direction of the Powerplants Committee of the National Advisory Committee for Aeronautics. Many of the engines were of the same make, differing in compression ratio or dimensions. The testing program included determinations of the brake-horsepower at various speeds and altitudes, or air densities, and the friction power, or the power required to operate the engine with no fuel or ignition at various speeds and air densities, with normal operating conditions of oil, water and the like. Some tests included determination of the effect of change of mixture ratio and of air temperature, and of different oils.

The difficulties caused by the necessity of using indirect methods to ascertain the effect of various factors are outlined. The test analyses and curves are presented. Results from many tests were analyzed and the relation between speed, air density and friction torque expressed as mean effective pressure, was studied. Running comment is made on the analyses and charted results, including consideration of pumping loss, variation of friction-horsepower with speed, the effect of change of air density upon the indicated power and the foot-pounds of indicated work obtained per pound of gasoline supplied.

Heat balance and losses are considered in considerable detail, the conclusion being that an increased utilization of the energy supplied in fuel must be obtained by an increase of compression ratio and the efficiency of combustion, as it seems almost impossible to reduce the jacket losses to an appreciable extent.

The analysis of the engine tests discussed in this paper is now in progress at the Bureau of Standards, being conducted under the direction of the Power-

[1]Bureau of Standards, Washington.

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plants Committee of the National Advisory Committee for Aeronautics. The complete analysis will appear as a report of the National Advisory Committee for Aeronautics. A large number of tests were made in the altitude laboratory, using aircraft engines. Many of these engines were of the same make, differing in compression ratio or dimensions. The testing program included determinations of the brake horsepower at various speeds and altitudes, or air densities, and the friction power, or the power required to operate the engine with no fuel or ignition at various speeds and air densities, with normal operating conditions of oil, water, etc. Some tests have included special variations, such as determining the effect of variation of mixture ratio, air temperature and different oils.

If indicator cards were available, many things could be seen directly, whereas without the indicator it is necessary to use indirect methods to ascertain the effect of various factors. The change of an operating condition such as speed, air density or mixture ratio, affects the indicated power liberated by combustion inside the cylinder in a direct manner; but it may or may not change the power required to overcome friction losses. For example, a change of mixture ratio sufficient to decrease the brake power has probably not materially changed the friction, if the speed and air density remain constant, but a change of air density at constant speed and with a suitable mixture ratio will change not only the indicated power but the friction power as well, and there will be at least two causes for change of brake power. In other words, when studying a change of operating conditions, the effect upon indicated power is the fundamental relation and the effect upon brake power is only a most important by-product. The friction losses are thus a promising field for investigation, not only because they must be understood in order to be reduced but because, at present, we must know their total amount to obtain a measure of the energy liberated inside of the cylinder. The term friction as here used includes not only the piston and bearing friction but also the power required to operate the valves, pumps, ignition devices, etc., and the pumping losses to charge and scavenge the cylinder. It would appear that the friction as measured when the engine is being driven by an electric motor might not be the same as the friction when the engine is operating, because of the effect of the explosion pres-

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sures and temperatures, the effect of the fuel upon the cylinder-wall lubrication, and other features. The values of indicated power obtained by adding the brake and friction power appear to be a good measure of what would be obtained with an indicator.

Test Analyses and Curves

Results from many tests were analyzed, studying the relation between speed, air density and friction torque, expressed as mean effective pressure. It was found that

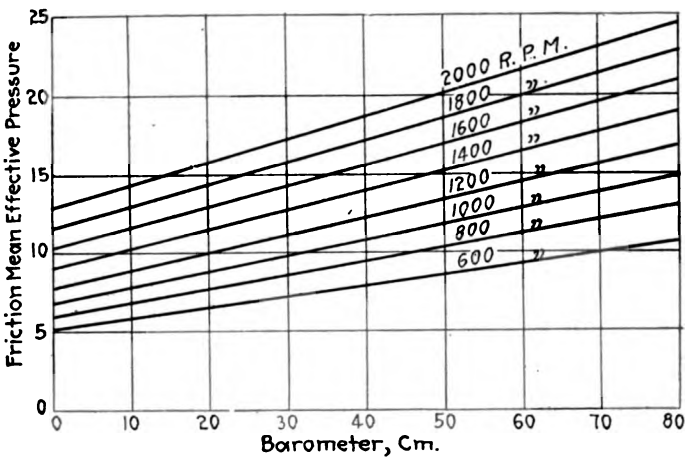

Fig. 1—Relation between Friction Mean Effective Pressure and Air Density

the friction mean effective pressure for a given air density was nearly a straight-line function of speed, and for a given speed it was also nearly a linear function of air density as shown in Figs. 1 and 2. The densities used in the tests ranged from 0.076 lb. per cu. ft. at ground level, or 75 cm. barometer, to 0.030 at about 30,000 ft. altitude, or less than 30 cm. barometer. By extending the curves of friction mean effective pressure for constant speed to zero density, a good idea was obtained of the friction when the pumping loss was zero. By subtracting the friction at zero density from the friction at another density and the same speed, a value was obtained which indicated the magnitude of the pumping loss. The estimates of the pumping losses thus obtained were directly proportional to the air density for a given speed. The pumping losses would be expected

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to vary in this way because the piston displacement for a given speed or volume is constant, and the difference of pressure between suction and exhaust, or the pressure per unit area, is proportional to the density. The volumetric efficiency enters as a factor, but if it decreases it will increase the pressure difference and decrease the density at the same time; thus its effect tends to be

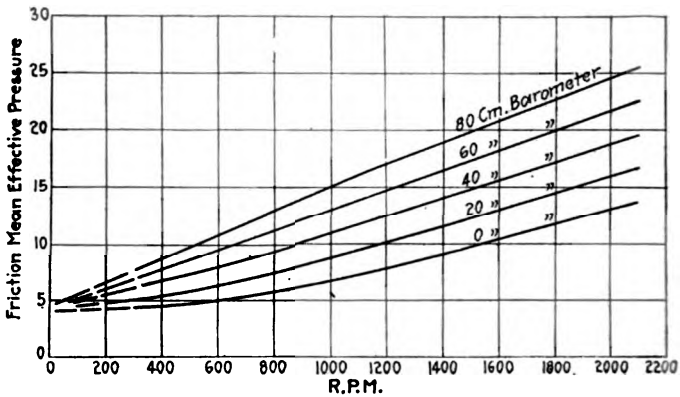

FIG. 2—RELATION BETWEEN FRICTION MEAN EFFECTIVE PRESSURE AND SPEED

small. The subject of volumetric efficiency is very elusive and is not touched upon here. Insofar as possible, this analysis has been made to eliminate dealing with volumetric efficiency as such, or so as to consider it a result, not a cause.

Some tentative curves for variation of friction horsepower with speed are given in A Study of Airplane Engine Tests, Report No. 46, of the Fourth Annual Report of the National Advisory Committee for Aeronautics, page 23, plot 27. These curves were made from rather meager data, but indicated an increase of friction horsepower with speed raised to a fractional exponent, up to a critical speed, above which the friction horsepower increased with about the square of the speed. More recent work, based upon more complete and reliable data, indicates that the relationship between friction and speed is not so simple, although similar. The logarithmic plot of friction horsepower against revolutions per minute in Fig. 3 is a continuously curving line whose instantaneous slope at any speed is dependent upon the engine; but in general the friction horsepower increases

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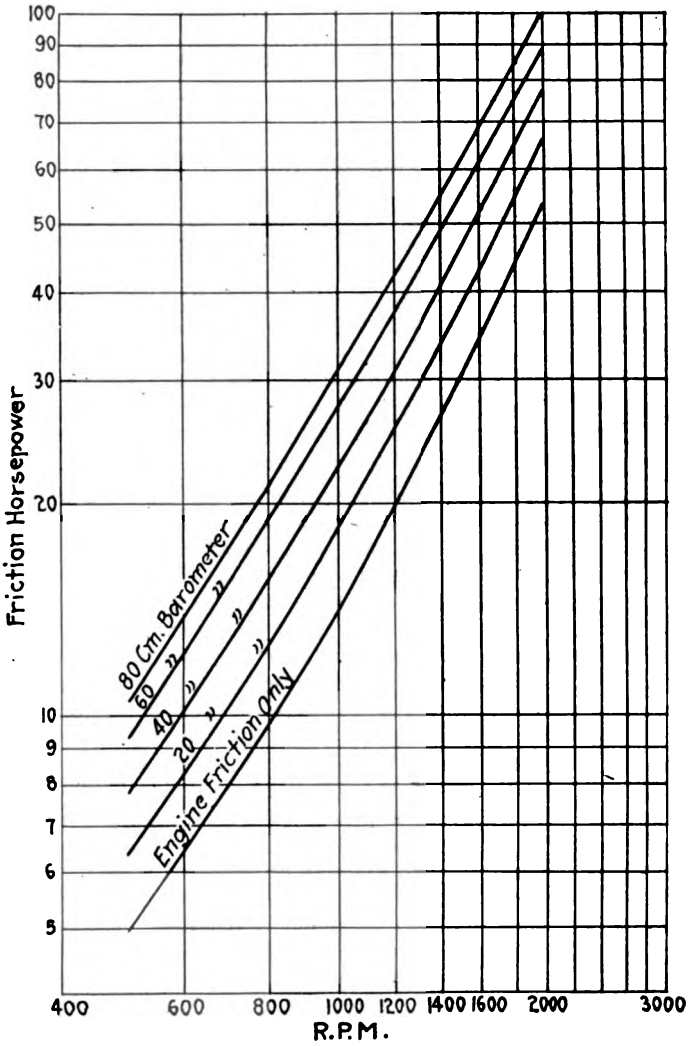

FIG. 3—RELATION BETWEEN THE HORSEPOWER REQUIRED TO OVERCOME FRICTION AND THE SPEED

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more rapidly at higher speeds, being about with the square of the speeds for small speed changes at the rated speed of the airplane engines which were studied.

There has been some question as to the exact effect of change of air density upon the indicated power. In National Advisory Committee for Aeronautics Report No. 46, because of the lack of data on friction horsepower it was practically assumed that this relation was one of direct proportionality. In the work now being done, the indicated power has been closely approximated by adding together the brake and friction powers. The form of the indicated horsepower versus density curves on pages 8 to 11 of report No. 46 are substantially confirmed in Fig. 4, in which the 5.4 compression ratio is indicated by a cross and the 7.2 ratio by a circle. Adverse conditions are usually encountered at extreme altitudes, a persistent difficulty being the rich mixture supplied by stock carbureters. This causes the indicated power to decrease faster than the density, above 20,000 ft.

Another way of showing the effect of density upon indicated power is to plot the indicated work against the weight of air supplied as in Fig. 5, in which the plotting points are shown by numerals indicating the ratio of air to fuel in the mixture. The points obtained with an open throttle have a circle around the numerals, while the others are from a throttled engine with the indicated mean effective pressure corrected to approximately the equivalent open-throttle value. The correction is based upon the pressure difference between the exhaust and intake manifolds. This method of plotting eliminates to a large extent the effect of speed and permits comparison of different engines. The resulting curve is not exactly a straight line. Excessively rich, or lean, mixtures will reduce the amount of work obtained from a pound of air and, with a given mixture ratio, when the weight of air supplied is reduced by decreasing the density, the power obtained from a pound of air is reduced. Some exhaust-gas analyses were available; these indicate that the denser the air the greater is the percentage actually used in the combustion. An approximation of the efficiency of combustion, or the degree of utilization of the air, was obtained from the amount of excess oxygen in the exhaust gas at various altitudes. The coefficient of utilization of the air at various altitudes was applied to the numerical values of the pounds of air supplied per cylinder per cycle, giving an idea of

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how the indicated work changed with change of the weight of air utilized in the combustion, shown by the lighter line on Fig. 5. It seems that they are directly proportional and the relation indicates no work at no air, whereas the relation of indicated work versus the weight of air supplied is a curve starting at no work for some air and becoming asymptotic to the direct proportionality, such as is shown by the heavier line on Fig. 5. Apparently, the indicated work obtainable is directly proportional to the weight of air actually combining with the fuel, providing combustion is complete

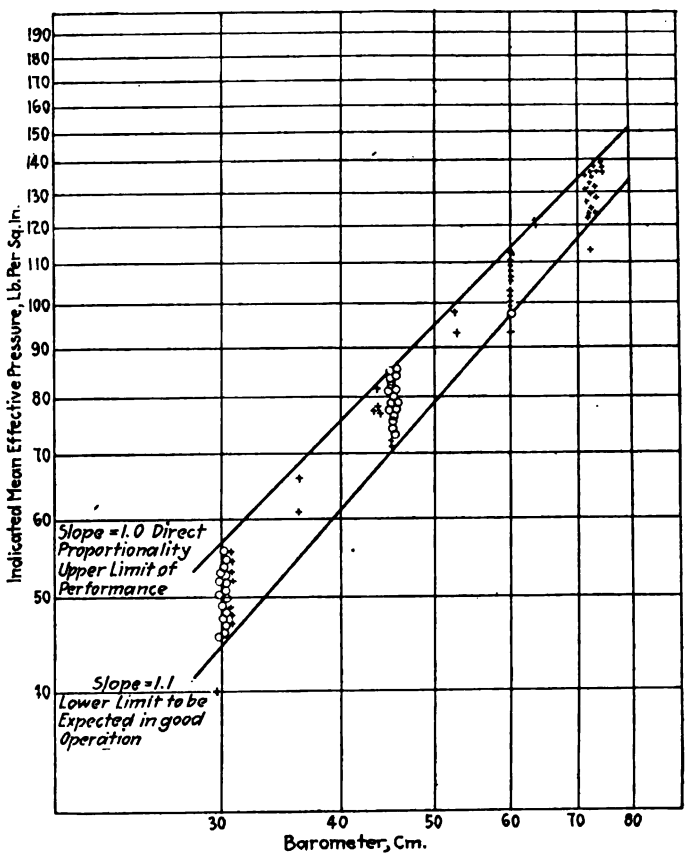

FIG. 4—RELATION BETWEEN THE INDICATED MEAN EFFECTIVE PRESSURE AND THE DENSITY OF THE AIR

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and the air and fuel are in suitable proportions. The proper proportions of air to gasoline for various altitudes are not definitely known, although it is believed that altitude has little effect. Much work has been reported recently, in engineering circles, upon the effect of change of mixture ratio upon power and thermal efficiency. The combustion is dealing with what can be called an effective mixture ratio, which cannot be directly measured. The usual measured mixture ratio includes more fuel than the effective mixture ratio, depending upon the kind of fuel, carburetion, distribution, speed, etc. Perhaps the difference between the actual and effective ratios is small in some cases.

The foot-pounds of indicated work obtained per pound of gasoline supplied steadily increases as the mixture ratio is made leaner, up to mixture ratios of 20 lb. of air to 1 lb. of gasoline. For still leaner mixtures the engine becomes erratic. A curve showing the relation of indicated work to weight of air, such as that in Fig. 5, is arithmetically the same as one showing the relation of work per pound of gasoline to mixture ratio, or the pounds of air per pound of gasoline. However, in some of the tests the weight of air was changed by altering the air density; in others by changing the speed; in still others by changing the mixture ratio or the air temperature at a constant speed and pressure. The conditions of the test may alter the appearance of the curves. Some of the latter tests, with changing mixture ratios, were plotted to the coordinates of work per pound of gasoline and mixture ratio. For the runs with varying mixture ratio, the foot-pounds of indicated work per pound of air supplied was found to be small at rich mixtures, such as 9 lb. of air to 1 lb. of gasoline, rising to a maximum at about 15 to 1 and then decreasing again. The leanest mixture employed was about 22 to 1. An increase of the compression ratio will increase the work obtainable from a pound of air. The efficiency of combustion increases with increase of density. If change of speed enters, it is a minor effect. The data available are not complete enough to answer quantitatively questions as to the possible effect of altitude or compression. The mixture ratio giving just sufficient oxygen for complete combustion of this gasoline is about 15.3 to 1. The gasoline used in all of these tests is of high volatility, meeting the 1918 specifications for aviation gasoline. No account could be taken of the quantity of oil which

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enters into combustion, although the exhaust-gas analyses and other evidences indicate that the quantity may be too great to neglect safely.

Heat Balance and Losses

Another interesting relation was shown on some tests wherein the temperature of the entering air was changed.

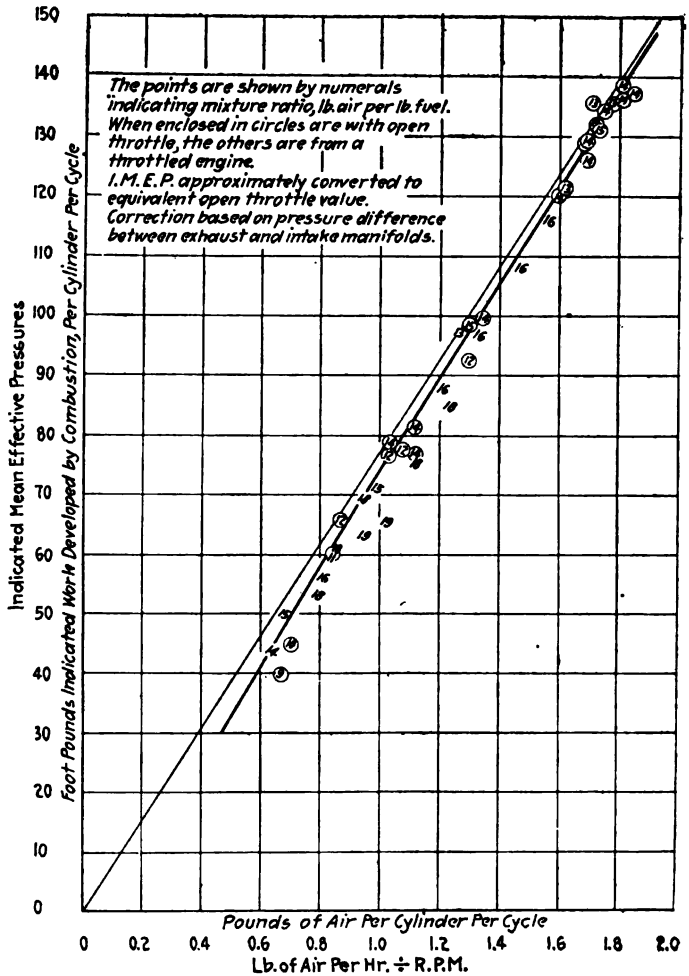
The points are shown by numerals indicating mixture ratio, lb. air per lb. fuel. When enclosed in circles are with open throttle, the others are from a throttled engine. I.M.E.P. approximately converted to equivalent open throttle value. Correction based on pressure difference between exhaust and intake manifolds.
Indicated Mean Effective Pressures
Foot Pounds Indicated Work Developed by Combustion, Per Cylinder Per Cycle
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Pounds of Air Per Cylinder Per Cycle
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0
Lb. of Air Per Hr. ÷ R.P.M.

Fig. 5—Effect of Air Density upon the Indicated Power of an Engine

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The indicated work obtainable from either a pound of air or a pound of gasoline is independent of the temperature of the charge in the manifold, for temperatures from 10 to 120 deg. fahr. This may not be true for still lower temperatures, as this gasoline does not seem to carburet well when the air entering is below 0 deg. fahr. Concerning the heat balance of an engine, the use of either the higher or lower heating value of the gasoline supplied as 100 per cent is open to serious objection, largely because changes in the air-to-fuel ratio alter the completeness of combustion and because the efficiency of combustion also is affected by change of the density of the charge at the time of ignition, the effect of altitude or compression ratio. The heat balance really should be based upon the heat made available by combustion.

S. W. Sparrow has already suggested the use of ratios of jacket and exhaust losses to the brake horsepower which work out very well for showing some relations. Carrying this idea further, heat balances were computed using the heat accounted for in the exhaust, jacket and brake, as 100 per cent instead of the heat supplied in the gasoline. The heat thus accounted for is nearly equal to the heat made available by combustion, the difference being the radiation, conduction and convection losses, a matter of only a few per cent. The amount of heat carried away by the cooling of the lubricating oil was roughly measured on one engine, and was about one-half of 1 per cent of the heat supplied in the gasoline. For compression ratios of about 5.4, the indicated power is about 34 per cent and the exhaust loss about 53 per cent of the heat accounted for, no systematic changes being noted for changes of speed, altitude or minor changes of mixture ratio.

Some computations have been made by Dr. Donald MacKenzie, based upon theoretical considerations and the exhaust-gas analyses at various altitudes. For the exhaust-gas analyses available, the mixture was proportioned for maximum power. Other mixture ratios would give different gas analyses, so that his computations are not strictly applicable to the altitude tests with stock carbureters. Using his values for the energy to be expected from the combustion of 1 lb. of O_2, the heat available from 1 lb. of air was found. In connection with the weight of air supplied to the engine, the heat made available by combustion was computed. Another heat balance

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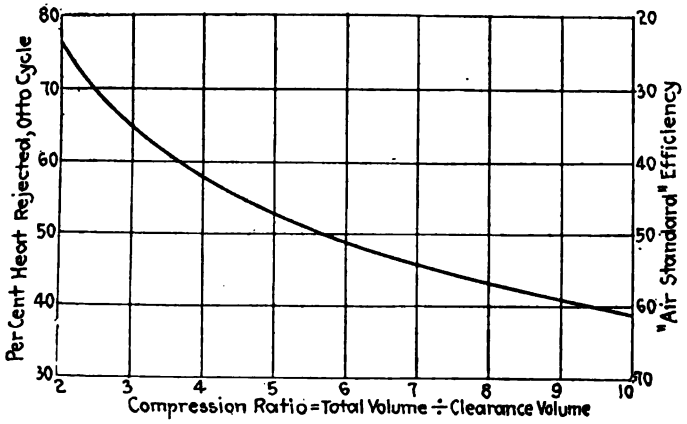

FIG. 6—RELATION BETWEEN THE HEAT REJECTED AND THE COMPRESSION RATIO

was based on this as 100 per cent, again giving consistent and nearly constant indicated thermal efficiencies of about 31 per cent and exhaust losses of about 50 per cent. These values appear to decrease slightly at altitude, possibly because the heat available was based upon maximum power mixtures while the tests had mixtures richer than the maximum power at altitude, with consequent less complete combustion.

The heat accounted for, that of the exhaust, jacket and brake, is less than the heat available, which is the weight of air supplied times the heat it makes available, by an amount of the order of 8 per cent at ground level. The residual by test, which is the heat supplied in the gasoline minus the heat accounted for, is of the order of 20 per cent at ground level. This indicates that about 12 per cent of the heat is lost in some manner. The radiation losses are probably of the order of 2 per cent. At 25,000-ft. altitude, the discrepancy between the heats supplied, available and accounted for, is greater.

The "air-standard" efficiency used as an ordinate in Fig. 6, or the efficiency of the Otto cycle, using air, assuming constant specific heat, is

$$1-\left(\frac{1}{\text{compression ratio}}\right)^{0.408}$$

Comparing the heat exhausted in the Otto cycle

$$\left(\frac{1}{\text{compression ratio}}\right)^{0.408}$$

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and the heat actually discharged in the exhaust of the engines for the same compression ratio, excluding unburnt fuel, it is found that the percentages are practically identical when the percentage of actual engine exhaust is based upon the heat available from combustion. At various times tests have been made in the altitude laboratory upon engines with compression ratios ranging from 4.7 to 1 and 8.3 to 1. Taking the exhaust as a percentage of the heat supplied in the gasoline, it is found that the different compression ratios gave exhaust at ground level as approximately 95 per cent of the theoretical heat rejection; 85 per cent at 15,000 ft. and 80 per cent at 25,000-ft. altitude. When the exhaust losses are approximately corrected to the basis of heat generated inside of the cylinder, they apparently coincide with the theoretical rejection for that compression ratio, as shown in Fig. 6. This would indicate that an increased utilization of the energy supplied in fuel must be obtained by an increase of compression ratio and the efficiency of combustion, as it seems almost impossible to reduce the jacket losses to any appreciable extent.

THE DISCUSSION

R. M. GASTON:—Have you made any tests which show the comparative performance with the variation in jacket temperature?

V. R. GAGE:—The tests for variations of jacket temperatures have been made, and so far we have been unable to get any very satisfactory answer. We know that the variation changes the friction considerably.

MR. GASTON:—Which way does it vary the friction?

MR. GAGE:—As the jacket temperature increases, the friction decreases because the viscosity of the oil drops, but the change is not always consistent.

MR. GASTON:—Were there any results which tended to indicate whether better thermal results accompany high temperatures? In other words, was a fuller expansion curve obtained?

MR. GAGE:—My impression is that this has not been carried out far enough to tell what does happen. As I said, changes in jacket temperature change the friction. We do not know what it is doing to the indicated power. We may be getting an increase of brake power by reducing the friction through the viscosity of the oil, but still the indicated power may remain constant. We will get

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better brake power, but if we originally used an oil of lighter viscosity we would have the same kind of an increase in brake power that was secured by increasing the jacket temperature.

MR. GASTON:—Your results seem to indicate that the engines are over-cooled.

MR. GAGE:—I will not say that. These engines were run at about a 160 deg. outlet.

MR. GASTON:—If the results are better when run hotter, why are they not over-cooled?

MR. GAGE:—My point was that hotter jackets thinned the oil down toward the danger point. The oil was selected for the probable range of jacket temperatures. Probably the largest friction loss is the piston friction. If we reduce the viscosity of the oils on a cylinder wall, we have less friction. In other words, the engines are lubricated with perhaps too heavy an oil, because we intend to play safe. We use too heavy an oil so as to take care of emergencies. These statements are my personal opinion, formed upon theory and rather meager experimental data.

S. UDALE:—Were any experiments made to determine whether the wire-drawing was more noticeable at altitude? Was the falling off of the mean effective pressure at high speeds more noticeable at great altitudes than at low? For example, was it greater at 30,000 ft. than at ground level?

MR. GAGE:—That would be shown on the indicated horsepower curve. The indicated mean effective pressure is practically proportional to the density of the air. As we rise in the air, we reduce the pumping losses and the other friction becomes less, but still the percentage of friction becomes greater. However, the amount is an engine characteristic. Curves for the Liberty engine would be different from those for the Hispano-Suiza.

MR. UDALE:—Was the critical velocity determined? I mean that with a given engine there is a limit in speed; the characteristic of any engine will eventually be flat. Of course, the average aeronautic engine is not run near that speed. Under those circumstances, if the speed was run up to such a point, would it be found that the horsepower was constant, that you had the peak?

MR. GAGE:—The volumetric efficiency falls off beyond a certain speed.

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MR. UDALE:—There is a flat characteristic.

MR. GAGE:—Above that we begin to have more friction of the air getting in. It cannot get in through the passages.

MR. UDALE:—Was this investigated? That is important in certain classes of airplane engines.

MR. GAGE:—Yes, the Liberty engine is run to 2000 r.p.m. The Hispano-Suiza has a peculiar sort of engine characteristic that seemed to tend to continue increasing, at least up to 2200 r.p.m. Still, there is a considerable wire-drawing, or manifold depression on this engine, which increases with speed.

MR. UDALE:—Did density have any influence?

MR. GAGE:—Perhaps your point is covered in that run with the engine throttled, where corrections were applied in order to compare throttling with altitude effects. In other words, this change of the mean effective pressure with density is directly proportional to the density of the air at the beginning of the compression stroke. There is no difference, whether the density is changed by going up in the air or by throttling the engine, either intentionally or unintentionally as by manifold restrictions, except for the relative change of suction and exhaust pressures.

MR. UDALE:—My point is whether there would need to be any different proportions in the area of the passages than if designing for ground-level conditions. Is the viscosity of the air any higher?

MR. GAGE:—I cannot answer that last question definitely because the throttle runs have been made only at 5000, 10,000 and 15,000 ft. It would seem that the best proportions might be the same at all densities. For, although the velocity through the manifold increases at altitude, the friction of the air in passing through becomes less as it becomes less dense. My estimate is that the passages would not need to be changed much. This subject involves volumetric efficiency, which also includes heat transfer from jackets, cooling effects from evaporation of fuel and other things. It is hard to tell the net result of change of only one of the factors.

J. W. STACK:—Were your friction experiments carried on with Liberty-engine specification oil?

MR. GAGE:—Yes; mainly with Liberty aero oil.

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MR. STACK:—Were viscosity comparisons made for different temperatures in the friction test?

MR. GAGE:—That subject has been investigated, but I cannot quote the viscosity figures. The actual viscosity, or temperature, of oil in the cylinder walls is not known, so no quantitative comparison of viscosity and engine friction can be made.

W. S. NATHAN:—What was the layout in the venturi for measuring air? Was the venturi directly on the carbureter for measuring the entering air?

MR. GAGE:—That is a point which explains why some of the data do not plot as well as they should, especially in connection with the work per pound of air. The air is drawn into the chamber through a box on top, where cooling and heating coils are located; it goes from that box through a venturi meter into the chamber. The venturi meter is connected to the carbureter intake by semi-flexible connections.

MR. NATHAN:—You are dependent on the suction of the engine for the action in the venturi. Have you taken any account of the inaccuracies of the venturi under the pulsating flows?

MR. GAGE:—The pulsating flows with the engines used are not very great. They are not as much as we often experience when using the venturi. The fact is that the flexible connection between the venturi and the engine leaked a little air. I found that we can get a 3 per cent leakage under the maximum unbalanced conditions. The pressure in the carbureter intake is balanced against the chamber pressure, and maintained practically the same. The maximum leakage would be, perhaps, 3 per cent in or out, depending on whether the venturi is under greater or less pressure than the chamber.

MR. NATHAN:—I take issue with you there, because I know that some tests have been made in which it was found that any sort of a reciprocating engine, or pump or compressor, has a very serious effect on the accuracy of the venturi.

MR. GAGE:—That is very true and the slower the pulsation is the greater the difficulty, because we are reading a manometer which is going up and down. A damping device is put in to stop pulsations, and some kind of a mean is what is read. We are then reading a pressure difference which is the mean of the upper and lower values. What should be used is the mean of the square

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roots of the fluctuations, instead of the square root of the mean of the fluctuations; the larger the fluctuation the greater the error. With eight or twelve cylinders pulling, at 1800 r.p.m., we get a very steady pull on the venturi. It is not a really serious fluctuation. If we try to use a venturi on a duplex boiler pump, running 20 strokes per min., we will have trouble from pulsations.

J. JANICKI:—You mentioned that comparative tests were made on friction, trying to allot the relative percentages of piston, gear and other frictions. Can you give an approximate idea of what those relative friction losses were?

MR. GAGE:—I have gone no further than to allot a certain percentage to the pumping loss. The bearing losses are small. The pumping losses for ground density at normal speed run a little under 50 per cent of the total friction losses.

MR. SHUMACHER:—You mentioned a new type of indicator; will you describe it?

MR. GAGE:—That was described at the annual meeting of the Society held at New York City in January, 1920. The indicator being developed at the Bureau of Standards was primarily conceived for use inside the altitude chamber. This necessitated a long-distance control, as no person can work inside of the closed chamber when the engine is running. It is of the diaphragm type, fitting into a spark-plug hole, and is slightly larger than a spark-plug. The connection between the engine cylinder and the under side of the diaphragm consists of a number of small drilled holes surrounded by a water-jacket. These holes are of very small volume so as not to alter the compression space. The diaphragm is placed between supporting grids, both above and below, limiting the deflection to a few thousandths of an inch. In the center of the top grid is an insulated electrode connected in a circuit through a telephone receiver and dry cell, the circuit being grounded at the diaphragm. The space above the diaphragm is connected to a pressure-tank or vacuum-pump system with indicating gages, so that a pressure can be applied, and measured, to balance the pressure on the under side exactly. A difference of a few tenths of a pound will be sufficient to allow or prevent contact of the diaphragm with the electrode, resulting in a click, or no click, in the telephone receiver. As so far described the device would be suitable only for maximum or minimum pressures. To obtain an indicator

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diagram, the electric circuit must include a commutator rotating with the engine or dynamometer shaft, and a brush contact adjustable to any crankshaft angle. The purpose of this timing device is to give a complete circuit through the telephone receiver only at the selected piston position, so that the cylinder pressure at this point can be balanced by the applied pressure. Thus, the pressures at each angle of the cycle can be measured, and an indicator diagram can be plotted from the data. This diagram will represent average pressures for the time consumed in taking the data.

MR. JANICKI:—Relative to the indicator, my experience has been in taking cards that the variation in the mixture gives various mean effective pressures. That is particularly shown on slow-running engines. In plotting the expansion curve with that type of indicator, would the factors or the average points obtained from that sort of a curve carry any great weight in real values in your opinion?

MR. GAGE:—Yes; the change in mixture ratio greatly affects the mean effective pressure.

MR. JANICKI:—Assuming an engine that is running at 500 r.p.m., before the pencil can be released from contact with the card in the ordinary indicator, six or seven or probably ten various expansion curves will have been drawn on that card, and they may vary 20 or 30 per cent. In plotting the curve, particularly on low-grade fuels, probably it is not so apparent, with high-grade fuel, as you pick these average points, would that be a large factor in the work?

MR. GAGE:—With various mixture ratios, on the one-cylinder Liberty engine and on some of the smaller engines, a smooth expansion curve is obtained. It is not a broad band. The maximum variations of pressure on the several contemporary expansion lines occur at the beginning of the stroke, and there is practically no variation of the expansion lines after the middle of the stroke, even when there is a variation at the start. The range of mixtures covered was from ordinarily lean to quite rich. However, the very lean mixtures are erratic; they may not explode at all or they may give a fairly full card. Such mixtures would not be tolerated in normal operation.

In using a gas-engine indicator of the ordinary type, expansion lines such as just described are seldom ob-

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tained because of the inertia of the indicator parts and the periodic vibration of the spring. If the rise of pressure in the engine happens on an upswing of the vibrating parts, the resulting explosion and expansion line of the card is too high, and, similarly, the vibrations of the indicator may partially counteract the effects of explosion. There are many different periods of vibrations of the ordinary steam-engine-type indicator, just as there are various overtones of an organ pipe.

MR. JANICKI:—I wanted to clear up this point, at fairly constant speed and load, the fluctuations being small. The data obtained would be of value.

F. C. ZIESENHEIM:—What temperature and pressure correction should be used for correcting horsepower to standard conditions for general-purpose test work?

MR. GAGE:—I have had many discussions on that score. There are a large number of variables and we must get back to indicated horsepower to make any logical correction. It appears that if we consider indicated horsepower, the temperature will affect the power to be obtained mainly as temperature reduces the weight of charge, because the power is proportional to the weight of charge. The pressure correction is made in the same way, simply as the density affects the weight of charge drawn in. That assumes that the suction and exhaust pressures maintain the same relations to each other, no throttling change, but change of density by altitude or temperature. For brake horsepower, no rough-and-ready rule that I know of can be applied unless we figure it in advance for the particular engine.

J. G. ZIMMERMAN:—On the question of flame propagation which comes in so strongly in all high-speed work, has anything been done on comparative work with the various grades of fuel?

MR. GAGE:—Comparing flame propagation for different fuels, the only thing that has been done is a recent test, when benzol was studied, and also some commercial gasoline was used. On commercial gasoline the one-cylinder Liberty engine knocked very badly.

MR. ZIMMERMAN:—One report given out by the Bureau of Standards on flame propagation gave the speed as 30 meters per sec. Does that fluctuate with slight change in the composition of the fuel? I am inclined to think that, in many of the so-called high-speed low-grade-fuel engines, designers are encountering the prob-

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lem of flame propagation without realizing what the trouble is. It is that the piston runs away from the flame if governed too high, in trying to operate on lower-grade mixtures.

MR. GAGE:—In the *Proceedings of the Institution of Automobile Engineers*[2] Professor Bone discusses selective burning and shows how the hydrocarbons break down into one product or another, passing through the different alcohols, etc., and finally may end with CO_2 and H_2O, if the combustion is completed. I am inclined to believe that in burning kerosenes some compounds ignite very quickly, but many of them hang fire and continue to burn, and there may be something of the effect you mention. We have been watching the flame propagation, in regard to detonation, but I must refer that explanation to Dr. MacKenzie.

MR. ZIMMERMAN:—Do you not think that the knock is due to the explosion of the first fuel constituents and that then difficulties come in because the mixture is not completely burned on account of the dilution of the remainder?

MR. GAGE:—Yes.

MR. ZIMMERMAN:—How much of the apparently delayed burning is due to the fact that we have a liquid instead of a vapor? That is, we have an imperfectly vaporized fuel in this heavier grade.

MR. GAGE:—That enters to a large extent, but the other factor is there, no matter if we do have the fuel vaporized, although I may be mistaken. I am basing this opinion upon what I have read, and my information has come mainly from British sources. Even if we have the fuel completely vaporized, we will have some of the effect of delayed burning.

MR. ZIMMERMAN:—It will be made much worse by imperfect vaporization, will it not?

MR. GAGE:—I should judge so.

MR. JANICKI:—I conducted some experiments in which I burned the gases at sub-stage, not supplying sufficient air at the first stage to complete the combustion, and obtained a sort of gasifying effect. I found that I could maintain a flame propagation at approximately 100 lb. per sq. in., open flow to the atmosphere, which gave me

[2]Paper entitled the Combustion of Hydrocarbons by W. A. Bone, vol. 1, p. 7.

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an influx of about 600 ft. per sec. at the secondary stage. I did this by first burning the charge and reducing it to a gas, then burning it a second time.

CHAIRMAN DENT PARRETT:—You have covered the point of unused oxygen in the exhaust gas; have you any figures of how that varies in accordance with conditions?

MR. GAGE:—The information on that subject is from tests with wide-open throttle and maximum power mixtures. Under these conditions, apparently about 98 per cent of the oxygen was used on the ground, falling off to perhaps 88 per cent at 20,000 or 30,000-ft. altitude. These values are qualitative, not quantitative. I hope that we may eventually have really definite information concerning combustion and exhaust-gas analysis. It is a very important phase of the work.

M. A. SMITH:—What was the explosion pressure on that engine? Could you record that pressure with the indicator you used?

MR. GAGE:—I cannot say definitely, especially in regard to these engines in the altitude laboratory. I have seen between 500 and 700 lb. per sq. in. on the one-cylinder Liberty engine when it was knocking, with commercial gasoline. It dropped down considerably below that when we again used export grade aviation gasoline.

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DESIGN OF INTAKE MANIFOLDS FOR HEAVY FUELS

By F C Mock[1]

The adoption of the present system of feeding a number of cylinders in succession through a common intake manifold was based upon the idea that the fuel mixture would consist of air impregnated or carbureted with hydrocarbon vapor, but if the original designers of internal-combustion engines had supposed that the fuel would not be vaporized, existing instead as a more or less fine spray in suspension in the incoming air, it is doubtful that they would have had the courage to construct an engine with this type of fuel intake.

That present fuel does not readily change to hydrocarbon vapor in the intake manifold is indicated by tables of vapor density of the different paraffin series of hydrocarbon compounds. This means that for certain vaporization of fuels containing elements of this density the intake manifold must be heated to a temperature slightly greater than the hand can bear continuously, and the present gasoline contains a large percentage of ingredients much less volatile than this.

To verify the belief that the fuel cannot evaporate in the intake manifold at ordinary temperatures, evaporation experiments were made using a large tank having a conical bottom, and further definite proof that the mixture remains wet was obtained by viewing it through a glass-sectioned manifold. Critical air velocities and the range of manifold velocities are then discussed at length and five specific points of design which seem to apply universally are stated and commented upon. The application of heat and the improved operation secured are then considered and illustrated, the different ways of applying heat being enumerated as the heating of the fuel before it issues from the carbureter nozzle; the heating of the air charge; and the heating of the intake-manifold walls.

In the early days of the motor car, the adoption of our system of feeding a number of cylinders in succession through a common intake manifold was based upon the idea that the fuel mixture would consist of air impreg-

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nated or carbureted with hydrocarbon vapor. If the original designers of internal-combustion engines had supposed that the fuel would not be vaporized, but instead exist as a more or less fine spray in suspension in the incoming air, it is doubtful whether . . . would have had the courage to construct an engine with this type of fuel intake, for it would have required very little imagination to foresee some of the difficulties which we have grown to tolerate in recent years because they have come upon us so gradually.

That our present fuel does not readily change to hydrocarbon vapor in the intake manifolds is indicated by tables of vapor density of the different paraffine series of hydrocarbon compounds, which show that even with elements of 58 deg. Baumé gravity and a boiling point of about 340 deg. fahr., the vapor density necessary for combustion can be obtained only with a vapor temperature above 110 deg. fahr. This means that for certain vaporization of fuels containing elements of this density, the intake manifold must be heated to a temperature a little greater than the hand can bear continuously; and our present gasoline contains a large percentage of ingredients much less volatile than this. I think it is the experience of everyone who has observed these conditions closely that we have almost no difficulty with "carburetion" when adequate mixture temperatures are obtained, and practically all the troubles in this line occur when the manifold temperature is lower than this point.

To verify our belief that the fuel cannot evaporate in the intake manifold at ordinary temperatures, we built a large tank with a conical bottom of sufficient size to hold about 2 lb. of air. We have repeatedly put into this 2/15 lb. of different samples of gasoline and allowed it from ½ hr. to 3 weeks to evaporate, blowing a draft of air upon the surface of the fuel in the bottom of the tank to facilitate its evaporation. With gasoline of 56-deg. Baumé gravity from Oklahoma crude, we were able to draw off about 60 per cent of the amount we had poured in; with 60-deg. Baumé gasoline from California petroleum we drew off about 30 per cent, both these experiments being conducted while the temperature of the tank was between 68 and 75 deg. fahr. Repetition of the experiment with different durations of time seemed to indicate that the vapor reached equilibrium in a very few minutes.

A final definite proof that the fuel does not evaporate

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in the manifold is obtained when you build windows or glass sections in the manifold and look at it. With the airplane gasoline used in the recent war, of about 68-deg. gra[illegible] an end-point of 257 deg. fahr., the mixture in the manifold was quite wet at 60 deg. fahr. and became completely dry, with wide-open throttle, at a temperature between 100 and 110 deg. fahr. With our mid-west gasoline of about 56-deg. gravity and an end point above 400 deg. the mixture is wet at and below 120 deg. fahr. at all throttle positions except extreme idle. When the throttle is closed it reduces the air density in the manifold, and if the mixture proportion of the carbureter is properly maintained less fuel will also be fed, so that a lesser vapor density will be required at partial throttle openings. For this reason the mixture will always be more nearly evaporated at closed than at wide-open throttle.

Certain benzol-mixture fuels now sold at Chicago are remarkable in that the manifold is dry and the mixture absolutely transparent at wide-open throttle at 80 or 90 deg. fahr.

Critical Air Velocity

When the fuel issues from the carbureter nozzle and sprays out into the air-stream, we believe that the condition of vapor saturation is reached very shortly after it leaves the nozzle, and all the fuel which can evaporate at that temperature does so. The remainder continues in the form of small drops which may either be carried along in suspension in the air-stream or, if the air draft is too weak, fall back and collect on the walls and the bottom of the air passage. Thus we have a critical air velocity below and above which the action in the manifold and the fuel feed to the engine are radically different. When the air velocity is sufficient to carry the fuel drops along with it, the temperature in the manifold is not so important and the ability to handle the fuel depends more upon the temperature in the cylinders. For instance, I have known of engines that will fire on kerosene almost as well with a cold small intake manifold of high air velocity as with a heated manifold, provided in both cases the cylinders are sufficiently hot. Also at high velocities the distribution of fuel to the different cylinders tends to follow the distribution of air fairly closely and is less dependent upon the contour of the manifold bends and curves.

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Below this critical air velocity the fuel after leaving the carbureter nozzle slows down, because in practically all carbureters the air velocity at the nozzle is higher than that in the manifold. In this slowing down the particles tend to drop out of the mixture and settle upon the walls, and when they strike any obstacle or pass around any bend they adhere to the walls and are not wiped off again by the air draft. This develops an accumulation and irregular flow of fuel along the walls, with the result that not only is the rate of fuel feed different to different cylinders, but it is often different *into the same cylinder on successive suction strokes.* Another particularly objectionable thing is the time lag between an increase of fuel flow at the carbureter and an increase of fuel flow at the cylinder. When the throttle is opened quickly from a closed position the increased air feed reaches the next cylinder on the suction stroke, but the unevaporated part of the increased gasoline feed does not reach any of the cylinders until several revolutions later. It is this erratic chronological variation of fuel feed to the cylinders that we blame largely for many of our difficulties in operation, such as gasoline getting past the pistons into the crankcase, an accumulation of carbon and fouling of spark-plugs. It is also the reason our present-day engines are very sensitive to every variation in ignition, because it seems that the more erratic the vapor content in the cylinder the more heat units are required in the spark to effect ignition.

Another condition which seems to assist the precipitation of the drops from the mixture is change in the direction of flow. In the multi-cylinder manifold, when the cylinders draw one after another in different directions, at each suction stroke there is a certain reversal of flow along the manifold, and at this time the air will slow down and gain velocity in a reverse direction much more easily than the heavier gasoline drops. We believe it is largely for this reason that the difficulties of distribution increase with the number of cylinders.

I have made a few experiments with glass manifold sections to determine what velocities are necessary to keep a fairly well atomized mixture in suspension. These indicate that under a steady non-pulsating air-flow a velocity of 38 ft. per sec. is necessary to keep the atomized drops off the walls in a vertical pipe. After passing around a bend or tee the requirements are more severe because the fuel has once been thrown on the walls by

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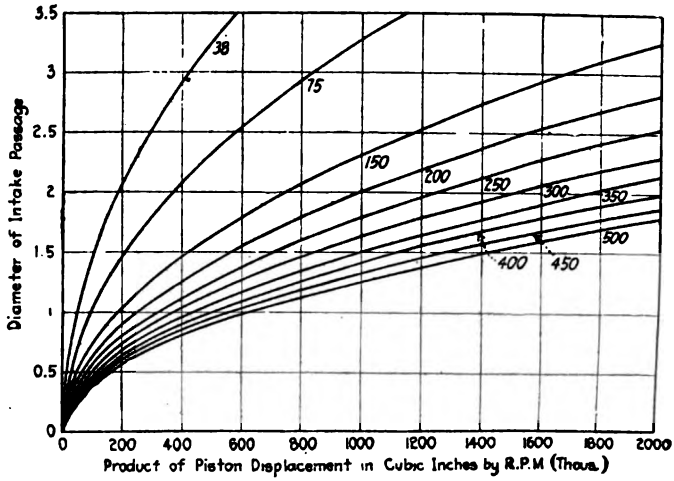

FIG. 1—CURVE SHOWING AIR VELOCITIES IN ENGINE MANIFOLDS

centrifugal force and must be wiped off again by the air velocity. We seem to find that to keep the intake manifold walls clean beyond a tee or fairly sharp bend requires a manifold velocity of about 75 ft. per sec. Under conditions of pulsating flow, with suction strokes which do not overlap, as with engines of four cylinders or less, we have reason to believe that the critical velocities are somewhat less, say about 80 per cent of the values above given.

To simplify the computation of air velocities we have prepared the curve shown in Fig. 1. The mean manifold velocity for any given engine will depend upon the total displacement of the engine, the revolutions per minute, the volumetric efficiency and upon the diameter of the intake passage. These curves have been made on a basis of 90 per cent volumetric efficiency which is probably in excess of that obtained with any of our engines at their normal operating speeds. Having given the piston displacement of the engine, we multiply it by the desired number of revolutions per minute and use this value as an ordinate, from which the air velocities corresponding to different diameters of intake passages may be easily read off.

RANGE OF MANIFOLD VELOCITIES

Our chief difficulty in manifold design comes because our engines must operate through a large range of

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speeds. If a car is designed to run at a maximum speed of 50 m.p.h. with a wide-open throttle and the intake manifold is designed for a velocity of 200 ft. per sec. at this speed, a velocity of 75 ft. per sec. will correspond to about 19 m.p.h., below which there will probably be some difficulty in getting proper carburetion with a cold intake charge, and a velocity of 38 ft. per sec. will correspond to 9½ m.p.h., below which it will probably be very difficult indeed to get the engine to fire properly with a cold manifold and a moderately lean mixture. It is, of course, possible to change the mixture vapor content, with a fuel containing a number of different elements, by increasing the rate of fuel feed, and thus increase the vaporization from the light elements fed.

I have heard of cars which were designed to operate with a cold manifold at 1 m.p.h. with a wide-open throttle. On this basis, with the above manifold, the air velocity would be but 4 ft. per sec., or 2⅔ m.p.h. An intake manifold with a velocity as low as this looks very bad. As you all know, a 2⅔-m.p.h. breeze can scarcely be felt; and I am quite sure the manifold walls would be covered with tears of grief because the gasoline could not get up to the cylinders.

It is possible to overcome these difficulties to a large extent and get a much wider operating range with a passenger-car engine by the proper application of heat. I simply wish to emphasize the futility of trying to design a high-speed passenger-car engine without giving careful attention to this application of heat. We can give an engine large valves, lighter reciprocating parts and efficient lubrication, but if we design the intake manifold large enough for high speed with no better heating means than a mere water-jacket, we will simply have an engine that will not operate a great part of the time when a man would like to drive his car. We were able to make airplane engines operate throughout a desirable range without heat on the manifold, because of the good grade of fuel used and the nature of the propeller load, which, when the engine speeds are low, permit running with partial throttle and more favorable evaporating conditions; but the same design would be absolutely impossible in a passenger or a commercial car with our present heavy fuels.

As previously stated, even distribution to the different cylinders of the liquid fuel content in the intake manifold is practically impossible at very low air speeds,

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while at extremely high speeds the fuel usually follows the air closely. There is a large intermediate range, however, through which the fuel distribution is quite definitely affected by the design and contour or map of the intake system, and in this analysis it is necessary to make a distinction between the effect of changes in contour and changes in area, which operate by varying the velocity. My own experience has probably been the same as that of most engineers, that in addition to the things we can understand about an intake manifold which affect distribution, there are a number of puzzling facts which we can scarcely account for at all; for one instance, the extraordinary effect that changing the order of firing may have upon the efficiency of a given manifold design. Some time ago we built a device by which we could blow a mixture of air and atomized water or gasoline through an intake manifold shape built in wood with one glass side. We also incorporated a hand or belt-operated set of valves so that the successive impulses of suction could be reproduced. With this we gained an entirely new idea of the action of the intake manifold and found what seemed to be a satisfactory explanation for a number of the anomalies we had observed.

The first thing we noticed was that, on account of the long distance and number of bends between the main carbureter passage and any given valve pocket, when the suction to a pocket begins, after having previously been inactive, the fuel does not immediately begin to flow through the valve, and by the time the flow of fuel drops and mixture has been established the valve closes, while the fuel piles up near the valve pocket and stops. On the next suction stroke this fuel, left over from the preceding one, goes in and another charge is drawn over from the carbureter passage ready to go in the next time. In other words, it is entirely improbable that, at most operating speeds, the unevaporated part of any given fuel charge completes its journey from the carbureter nozzle to the cylinder during the same suction stroke that its air charge does.

We also seemed to find that whenever the fuel and air mixture comes to a tee or a point where the passage divides, and when there is a flow in one direction while the other division is inactive because its intake valve is shut, as a result of the eddy at this point a little pool of fuel is formed in the passage which is inactive. Then when the intake valve of the previously inactive cylinder

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opens, the sudden inrush of air draws in not only the fuel brought there by the previous air charge to this same cylinder but also the fuel deposited at the mouth of this individual passage by the suction of the neighboring cylinder. I think this is why we usually find that when the timing and design are such that two cylinders follow each other at unequal intervals in drawing from the same valve pocket, the one following the longer interval usually gets the richer mixture; of course, under the conditions of low velocity previously described. I would not say that the fuel literally drops down to the bottom of the manifold and forms a pool, because it does not always have time to do so; but it does stop moving, which gives, to a certain extent, a similar effect. A window in the intake manifold shows a rapid flicker of the atomized fuel, changing its direction back and forth, even when the walls of the manifold are dry.

I would like to be able to evolve a few rules by which an efficient intake manifold design could be made. But the problem is so complicated and the individual requirements of design so varied, that this is practically impossible. The only definite recommendation I can make is that before proceeding with the actual construction of an engine it would be well worth while to have a pattern-maker construct a wooden model of the contemplated manifold to scale and in the exact position that the finished manifold will occupy, and then discharge a mixture of air and water through it and notice the action, with the cylinder ports opening in the order of firing. Much can be learned about the distribution by turning on the air in spurts of a second at a time as the valve ports open in succession. It will usually be found that there is a slight delay before any liquid fuel discharges from the ports, and the cylinders which are getting the richest fuel charge will respond most quickly and in the greatest volume. A great deal can also be told about the flow of the fuel by the manner in which it comes out of the port, whether at one side, the top or the bottom, or evenly distributed throughout the air column.

There are a few points of design which seem to apply more or less universally and may be worthy of enumeration here.

(1) When the design permits, no two valves should follow each other in the same pocket, unless they operate at equally spaced intervals of engine rotation

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(2) The distance from a tee or point of division to each valve should as nearly as possible be the same. More important and less difficult to obtain, the angle of bend and amount of vertical rise should also be approximately the same. It is very bad to feed some cylinders out of the top of a manifold passage and others from a gradual rise at the ends

(3) Avoid any sudden enlargements, particularly in the vertical rise

(4) Make the bends of as large a radius as possible. The total resistance of the manifold to air-flow is the sum of the bend resistance and the straight passage resistance, and by easing up at the bends it is frequently possible to use a smaller diameter and higher velocity throughout, without decreasing the maximum power capacity

(5) Most important of all is the proper application of heat, to be discussed more fully in later paragraphs

The actual sizes will depend, of course, upon the intake velocities used, and these are contingent upon the heating. For the present-day motor-car engine, which is expected to operate on a range of full throttle of ten to one, I would make the intake manifold velocity not less than 250 ft. per sec. at the maximum normal operating speed, and I would try one with 300 ft. per sec. If a properly designed hot-spot is used, it may be practical to decrease this velocity to 190 or 200 ft. per sec. without any loss in efficiency at low-speed pulling.

It will be noted that it is often very difficult to conform with these requirements, when the intake manifold is cast integrally in the cylinder block. With the grade of fuel available some years ago, inequalities in distribution could be compensated for by the rise in manifold temperature due to the water-jacket, but now the water temperatures are no longer adequate and the concessions which it is necessary to make to foundry practice nearly always prove seriously detrimental to the operation of the engine. There are a few engines whose performance proves that it is possible to secure a fair distribution with an "enbloc" manifold, but I am sure that in every case the performance would be even better if the manifold were properly built outside.

One thing which I shall personally avoid is spiral bends or ramshorn shapes, not because some of them have not been known to work well, because they very definitely have, but rather because of the difficulty of knowing in

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advance how they are going to work. The effects of gravity and of centrifugal force may either oppose each other or combine, according to the speed. In several cases we have spoiled the action of the engine to an extent almost unbelievable by the use of an improperly shaped spiral bend, and in one case we remedied the trouble by an alteration so slight as to be hardly noticeable. In fact, it was a change which had to be shown rather by a model than a drawing. I also prefer to make the manifold as nearly as possible in one plane, which permits a model to be made with one side of glass and usually works out to a neat appearance when finished.

One point to be taken into account is the effect of having the throttle, if of the ordinary butterfly type, near a point of division. Care should be taken that the throttle in a partly open position does not deflect too much of the liquid fuel stream into one part of the manifold. Unless the point of division or tee is plain in shape and well heated, the throttle ought to be at least 4 in. below the tee; it is even preferable to have the throttle crosswise of the tee. We have nearly always had trouble when the tee bend had a deflecting corner in the center, what I might most easily describe as a Y-bend.

Application of Heat

The proper application of heat is difficult under ordinarily accepted limitations, because of the great range in temperature variation in the many different conditions under which an engine is operated. All of you know the great variation in water temperature encountered on a single spring or fall day; and the heat of the exhaust at any given point can vary more than 500 per cent, between closed-throttle running in winter and open-throttle running in summer. With this variation in temperature we have the condition that a rise of 50 deg. fahr. will cut down the density of the air charge, and the power, 10 per cent; and a rise of 30 deg. in the mixture temperature at low air velocities may make all the difference between perfect operation and continuous trouble. This sensitiveness to temperature change on the part of the fuel system, in conjunction with the very great temperature change encountered in the engine, is, I think, the reason so little progress has been made in the application of heat to our fuel systems in the last few years.

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The different ways of applying heat may be enumerated as follows:

(1) Heating the fuel before it issues from the carbureter nozzle
(2) Heating the air charge
(3) Heating the intake manifold walls

As to the first we definitely and positively advise against any attempt to heat the fuel in the float bowl of the carbureter, because fuels in many sections of this country contain a small percentage of very volatile elements, casing-head gasolines being a sample. The amount of heat that is necessary in the carbureter to handle the heavier elements will make these light elements boil rapidly in the nozzle, which totally upsets the metering of the carbureter, causes the engine to backfire and practically makes the car unusable until the heat supply is removed.

Heating the air has the disadvantage that it applies equally or in greater measure to high-entering manifold velocities, when it is scarcely needed, than to low air velocities when it is most needed. This results in there being a considerable loss of power at high speeds, if the air supply is sufficiently heated to give good operation at low pulling speeds. Nevertheless, preheating the air to a certain degree is advantageous in all except hot summer weather, and I believe that the present practice of taking the intake air from a small heating chamber surrounding the exhaust pipe is about as effective as necessary and can scarcely be improved. It is, of course, necessary to provide a means for disconnecting the hot air by opening additional cold-air vents in hot weather or in hot climates; also in case of the possible use of casing-head gasolines.

The third method mentioned, of heating the manifold walls, appears to me to offer the greatest possibilities, because it seems to work out in practice that the delivery of heat to the fuel is most efficient when the air velocities are low, just when this action is needed, while at high velocities the effect is less marked. This, however, is only true if the design is properly made, for there are several very important considerations which must be followed. The heat must be applied only on a relatively small area and at points where the fuel gathers. It is well known that when the atomized mixture passes around a bend or through a tee, the heavy particles will go to the

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outside; also that, after the fuel is once condensed, it tends to follow the laws of gravity and seek the bottom of the passage. This means that the vertical portion above the carbureter, the outside of the bend or tee and possibly a small portion of the bottom of the passage just beyond the bend, are the places to heat. If these walls are heated to a temperature of 250 deg. or higher, the fuel particles will strike them and fly off or fry off as a fine fog of smoke and remain in this condition until the mixture reaches the cylinder. In order that this temperature may be quickly attained after starting, and in cold weather, it is necessary to take a considerable portion of the exhaust heat. This we have obtained by heavy ribs projecting into the exhaust passage and by making sure in all cases that the exhaust circulates through these ribs. To keep from getting too much heat in summer under full load with this effective method of heating, it is absolutely necessary as previously stated that the heating area be confined wholly to the places enumerated above, where the heavy fuel particles strike. A good rule is 1½ sq. in. of heating surface to each 50 cu. in. of piston displacement. To hold the fuel at this point longer and insure a more complete heating at low temperatures, ribs or baffles are provided to obstruct the flying off of the particles.

Fig. 2 shows an elbow heated by this method. The carbureter is attached at the bottom and the mixture is delivered horizontally to the intake manifold at the right, while the exhaust comes in at the top and escapes at the left.

Fig. 3 shows the same construction applied to the tee of the intake manifold. The exhaust enters from the top and escapes to the rear through an outlet which is not shown. In both these cases it is advisable to make the exhaust connection as short and direct as possible, and the larger the size the better. However, the exhaust outlet can be small, a ¾-in. iron pipe being ample in size. With this size pipe, perhaps on account of the cooling and the baffling effects of the ribs, the sound of the exhaust escaping through this passage is scarcely noticeable.

Fig. 4 shows an attachment that is badly needed on many of the present-day motor trucks. To obtain a good governor location and gravity feed to the carbureter, the latter is frequently mounted very low with a cold vertical section of the intake passage 1 ft. or more long, which

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acts as a natural condensing chamber for the fuel. This illustration shows a heating element, to be located between the governor and the carbureter, in which the exhaust is passed through a central cross-tube over which the intake charge must pass and upon which the gasoline particles will strike. The axis of the throttle should be crosswise to the direction of the tubular passage, as shown, so that at partial throttle openings the fuel will be sure to strike the heated surface.

A very important point about the installation of such a device is that the exhaust must actually reach the hot-spot. If the piping from the exhaust manifold to this point is 1 ft. or more in length, the natural resistance of the line will be high in proportion to the main exhaust pipe and very little exhaust will pass through it, with the result that it will not heat up with closed-throttle

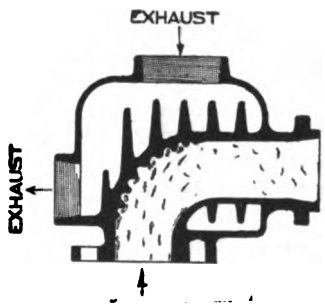

Fig. 2—Heating an Elbow

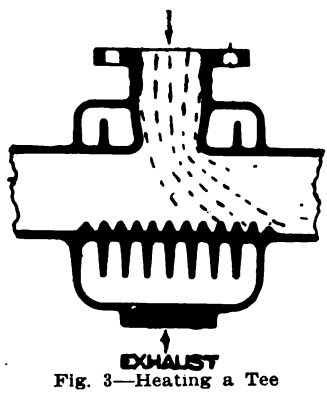

Fig. 3—Heating a Tee

APPLICATION OF HEAT TO AN ENGINE MANIFOLD

operation, but only after the engine has been pulling hard. Therefore, when the pipe to the hot-spot is necessarily long it should be made as large as possible, 1½ to 2 in. in diameter, and protected from any loss of heat, either by wrapping the outside with asbestos or by putting an additional outer sheet metal or flexible tubing casing around the outside. It will probably be found necessary also to restrict the main exhaust line by a bushing or flat plate with a hole in it, to about the same size so that at least half of the exhaust will pass to the hot-spot. It is remarkable how *very little* heat will pass through a long pipe connected into the exhaust manifold, unless some additional restriction is placed beyond this

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connection in the exhaust line. Inasmuch as the average exhaust line could be reduced to one-quarter of its area without either affecting the power or overheating the engine, it is perfectly safe to make the above restriction in the main exhaust outlet.

Improved Operation Secured

The use of these devices has improved extraordinarily the operation of a number of cars upon which we have tried them. We have been able to make six-cylinder engines warm up very quickly in the coldest weather. As the hot-spot is so limited in area it does not heat the intake charge more than 20 to 30 deg. fahr. and we have actually had a gain in power instead of a loss, probably because of better distribution and the fact that it was possible to use lower manifold velocities with less reduction of volumetric efficiency. The fuel economy is very much better indeed, both because the carbureter can be adjusted much "leaner" and because the dash-control of the mixture is used so little. Another reason the economy is better is that the engine remains in better condition. There is less carbon deposit, almost no spark-plug or ignition trouble, and it is no longer necessary to change the lubricating oil every two or three weeks. I firmly believe that three-fourths of the service work performed on passenger cars and motor trucks today would be eliminated if their intake system were modified along these lines.

I believe and hope that the time is coming when the service departments of each responsible motor-car and motor-truck manufacturer will develop fittings and connections of the nature indicated to replace the equipment of cars now in service. After the patterns and tools are once made the cost of production is low and the application could probably be made in half a day, so that the complete installation should not cost over $10 or $15. I know of no other way in which an equal gain in operation, satisfaction and efficient service can be obtained for three to four times the price, and I am sure that the company which first makes the effort will be well rewarded.

One serious difficulty is often encountered in the application of a hot-spot to present cars, the difficulty of piping exhaust heat across an engine when the carbureter and exhaust manifold are on opposite sides. To make the exhaust pass through this branch it is necessary that

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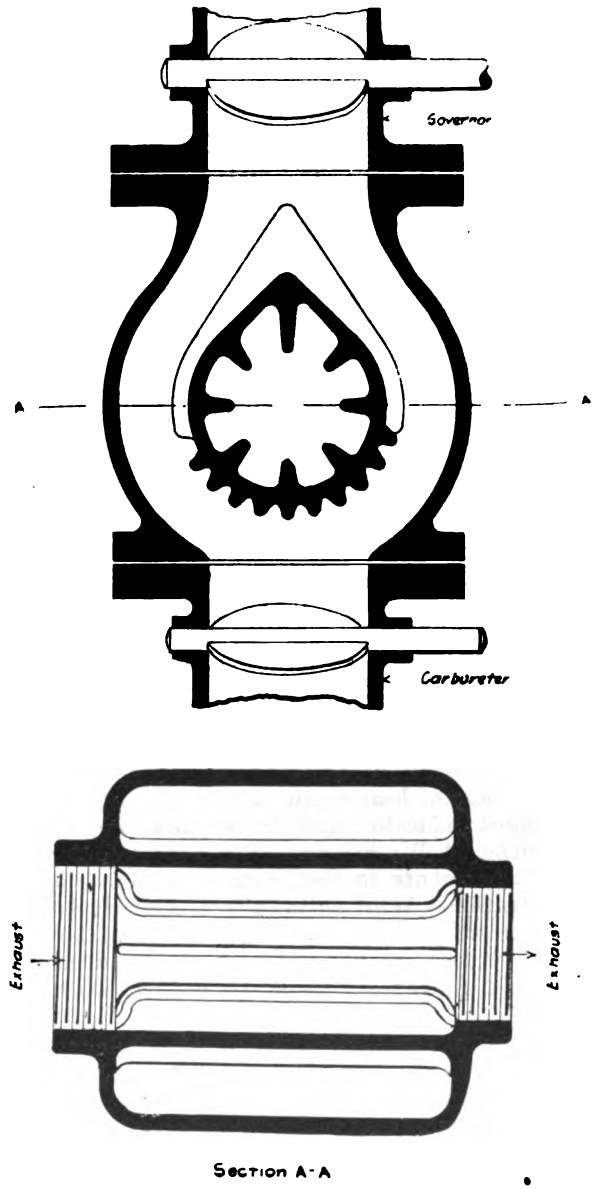

FIG. 4—HEATING ELEMENT BETWEEN THE GOVERNOR AND THE CARBURETER

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it be almost as large in capacity as the main exhaust line, which leads to expense and to difficulties in silencing. We are making experiments as to the amount of restriction that can be placed upon the exhaust line to force heat across an engine in this way, but at present I can only say that in every case where it is possible to do so the carbureter should be placed on the same side of the engine as the exhaust manifold.

THE DISCUSSION

PAUL KROESING:—Many engineers advance the theory that when there are too many hot-spots at the intake, the pressure in the cylinder is reduced.

MR. MOCK:—Yes, if the hot-spots are too large. Sheet metal cannot possibly get too hot as long as liquid is on it.

G. W. SMITH:—A new device with many little pockets is being made for the Nash engine. The light fuel goes through and the heavy drops into the pockets which are heated. The heavy immediately fries up and joins the light fuel, and every portion of fuel is thus utilized.

CHEMICALLY TREATED FUELS

J. G. ZIMMERMAN:—Several years ago it occurred to us that by treating fuels chemically great improvements could be made, but this idea was suppressed. Nevertheless this process is coming and the supply of fuels now available will soon be enlarged by chemical treatment. Then the study of heating the manifold must be repeated and changes made to apply to the new fuels. Experiments made at Washington were very satisfactory in spite of statements to the contrary made by the Fuel Administration. With chemically treated fuels used in the proper way, greater mileage can be obtained than with the highest grade of gasoline now produced.

W. G. GERNANDT:—How do such fuels work in cold weather?

Mr. ZIMMERMAN:—The fuels were of summer grade, but the treatment can without difficulty be controlled to produce any desired fuel. This is a new field that will bear the closest investigation. A great many devices now necessary while using present-day fuels will be supplanted.

D. S. HATCH:—Is there a possibility that such fuels will be put upon the market commercially?

MR. ZIMMERMAN:—Plans for the largest working

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plants are complete and experimental plants for producing 2000 gal. per day are ready now.

C. B. PAGE:—Has the use of steam really accomplished any great effect or any advantage over the hot-spot?

D. L. ARNOLD:—I once had an idea that steam would be a good thing and made an experiment on a two-cylinder engine. I put a jacket on it and tried to take all the steam into the engine. It did not work. It reduced the horsepower from 60 to 45.

INCREASING THE UTILITY OF THE TRACTOR

BY ARNOLD P YERKES[1]

The comparatively slow introduction of mechanical power for farm operations has been a surprise and a disappointment to many. It is easily understandable why the deficient machines failed to sell but not so clear why really efficient outfits failed to make greater headway. No one can make a thorough study of the existing situation and conclude that any or all of the reasons given are even in a large part responsible for the slowness in adopting the tractor more generally on the farms; it is obvious that there are other strong influences. Most of these are connected with the farm business itself and, by considering the matter in relation to the individual farmer rather than farmers as a class, these influences become more clear.

Farm-tractor adoption data are then presented, the statement being made that, in addition to the fact that there is such a plentiful supply of work animals that universal adoption of mechanical power must await their passing, three other influential factors are necessary to bring about the more general utilization of the tractor. These factors are then specified and discussed.

The farmers' income is analyzed, critical comment upon the subject of human versus mechanical labor being made. Changes in equipment and methods are advocated and the current efforts to increase tractor utilization are detailed, the conclusion reached being that the farmer should be told how to change over from a small and inefficient plant, wherewith human labor is being wasted, to a larger and efficient food-production organization with which he can practise the same principles of quantity production that are prevalent in large manufacture today.

[1]International Harvester Co., Chicago, Ill.

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It is now more than 15 years since the gasoline tractor was first used in quantity for farm work. The tractor is, therefore, almost as old as the automobile and is really older than the motor truck. But in spite of the fact that several million automobiles are in use and a million or more motor trucks, the number of farm tractors in use at the end of 1919 will probably be 100,000 short of the half-million mark.

This comparatively slow introduction of mechanical power for farm operations has been a surprise and a disappointment to many people. Numerous companies have been organized to manufacture tractors under the belief that the business was sure to grow at a tremendous rate, and that there would be room for many companies to manufacture the tractors they had been told that farmers were waiting to buy, and which they must have at once to replace the expensive horse. Company after company has become involved in financial difficulties because the farmers did not take advantage of their opportunity to relieve themselves of this burden. A great many of these early mechanical horses were rather freakish and incapable of meeting the requirements of the farmer; but in addition to the rather long list of machines of poor design and construction, a few, even among the early makes, were sold in large numbers and proved a profitable investment for the farmers.

It is easy to understand why the machines which were deficient failed to sell. It is not quite so clear why the really efficient outfits failed to make greater headway. Some have blamed the poor tractors and their effect upon the farmers for the slow progress made in introducing those of more satisfactory design and quality. Others have thought that no really efficient tractor of just the right size and possessing sufficient all-around usefulness had been produced. They have professed to see a wonderful and immediate market for the tractor that would fully meet the farmers' requirements. Others still believe, or profess to believe, that past and present tractors have been lacking in quality of material and workmanship to such an extent that they failed to meet the farmers' requirements for durability, and that what is needed to give the business proper acceleration and increase sales is the attainment of the highest possible quality, so that the tractors will be capable of working steadily for several seasons on farms, without danger of delays and expense due to breakdowns and repairs.

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No doubt the failures of tractors to succeed on some farms has had the effect of making neighboring farmers rather slow to try one, but certainly this cause alone has not been either wholly or in large part responsible for the slow adoption of tractors during the past several years. It may be true also that some farmers are waiting for a tractor capable of a wider variety of work than those now available, although it is difficult to conceive of a wider range of usefulness than is claimed for some machines now on the market, but which do not seem to enjoy any greater rapidity of distribution than other machines of more conservative design and with a shorter list of claimed accomplishments.

As to the need of better quality to increase sales, the tractor would be in a class by itself if highest possible quality were essential to secure its general or extensive adoption. In almost every line of manufactured goods there is a wide range of quality, and this variety exists because the trade demands it. No matter what the article, there is usually a choice of quality ranging from the poorest to the best for which any demand exists. For a few dollars a watch can be purchased which will keep time fairly well and answer all practical purposes. For several hundred dollars one can buy a Swiss hand-made watch which will not vary more than a fraction of a second per month. There is a demand for each kind, but the lower-priced ones sell in the greatest numbers. This should not be overlooked, for it holds true of many other things besides watches, not excepting tractors. Many men who buy watches with high-priced works, and add still further to the cost by getting a handsome case, will, when buying a pocketknife, get a comparatively cheap one, perhaps paying more attention to appearance than to real quality, because they have little use for a knife. But others will spend a greater amount for one having blades of higher-quality steel, because they feel that it pays them to get a knife of good quality. And so with other articles, depending upon the need for their use. The quality depends, to a large extent, upon the amount one is willing to pay. The tractor is no exception. There is some demand for a tractor of highest possible quality, but there is no more reason for having all tractors of this superlative quality than for having all watches Swiss hand-made, or all jackknives hand-forged from crucible steel.

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Farm-Tractor Adoption Data

No one can make a thorough study of the existing situation and conclude that any or all of the reasons mentioned are even in a large part responsible for the slowness in adopting the tractor more generally on the farms. It is obvious that there are other strong influences. Most of these are connected with the farm business itself, and by considering the matter in the light of the individual farmer rather than of farmers as a class, these influences become more clear. Considering the subject in its broader aspect and using available statistics, one of the strongest reasons becomes quite obvious. There are on farms in the United States between 300,000,000 and 350,000,000 acres tilled each year. This acreage varies according to market conditions and also according to weather conditions during working seasons. There are about 25,000,000 work horses and mules on farms in this country, or at least one work animal for every 14 acres of tilled land. On a great many general farms where horses are the sole source of power for field work, only one animal is kept for every 30 acres of tilled land and the work is carried on in a very satisfactory manner. It would thus appear that there is at present an abundance of animal power available for farm operations. In spite of the enormous increase in the number of automobiles, motor trucks and tractors, the total number of horses has shown no great decrease, although the latest Government figures show for the first time in several years a decrease in the number of work animals. But the point is that these animals are in the country and, since the average life of a work horse is about twelve years, at least half can be expected to be still available five or six years hence, and their colts will continue to be raised in large numbers, although in smaller numbers than previously.

The price for work horses has decreased gradually for several years, owing to the high cost of feed and the falling off in the city demand for horses because of the increased use of motor trucks for city hauling. Farmers will not kill off their horses simply to buy tractors; neither will the individual farmer sacrifice his work stock to buy a mechanical powerplant, although he may believe it might prove more efficient and satisfactory than horses. In addition to the very impor-

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tant fact that we have such a plentiful supply of work animals that universal adoption of mechanical power must await their passing, there are three other influential factors necessary to bring about the more general utilization of the tractor.

(1) A lower first cost, or greater financial return for farmers, or both

(2) Perfection of machines and attachments for the tractor and motor truck which will permit their use to better advantage for some of the work for which horses are still used, and also reduce the human labor required

(3) Informing farmers how to reorganize and enlarge their farm business by crop rotation, etc., to utilize the tractor to advantage and also maintain soil fertility

Any suggestion of lower prices for tractors under present conditions seems unreasonable, but either these must come before tractors will be used in really great numbers or farmers as a class must receive greater returns, to make more of them financially able to purchase tractors at present prices. The latter alternative may not appear logical to those who believe farmers as a class are able to buy almost anything. Such a belief is, however, far from being in accord with actual facts. Many people make the mistake of judging farmers as a class. They may have an intimate knowledge of a few individual farmers, their financial circumstances and general surroundings. If they visit friends or relatives on a farm, they are apt to visit those who are more prosperous than the average and have a home and general surroundings conducive to such visits. All farms are not of this nature. A large percentage of American farmers are tenants. Among these tenants many have been hired men or farm boys, who have had little money to begin farming and were gradually working their way up. If they have lived in a community a few years and shown themselves honest and industrious, they can often obtain a farm either on shares or for a small cash rental, even though they have very little stock or equipment. Many retired farmers are willing to advance money. They are accustomed to increasing their powerplants by raising

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colts, or by purchasing young colts, perhaps working in part payment for them and raising them as cheaply as possible on pasture and roughage otherwise of little value. Many of these tenant farmers are in no financial position to buy tractors even if desirous of so doing. It is true that many of them have sufficient credit to buy a tractor, and the same holds true of many who have passed through the tenant stage and acquired title to a farm, although under a heavy mortgage. A loan to an honest and industrious man with a family is always reasonably safe, and country bankers know this. However, many of these men and their wives hesitate to incur more indebtedness until they have paid off some of the mortgage and perhaps obtained necessities and luxuries which they feel they would rather have than a tractor. In some States nearly half the farmers are renters. A large percentage have comparatively little capital and are making, as a rule, a very small net income. Their available surplus can always be used for buying numerous articles for the comfort and enjoyment of their families, and it is small wonder that so few of them purchase tractors.

In spite of all reports about profiteering on the part of the farmer, the returns on his invested capital and for the amount of work he puts into crop and stock production have been, as a rule, pitifully small. Most farmers today have begun with little or nothing and have gradually acquired land, work stock and other livestock. It is an exception if they have any great sum of money to invest at any time; and, when they do have money to spend, there are many ways in which to spend it. While farmers as a class are getting greater returns than was formerly the case, they must also pay much more for almost everything they need. They are also living on a somewhat higher plane, and naturally do not propose to return to former conditions simply to have money to invest in some particular machine. It is no longer considered wise to keep children out of school following the sixth or seventh grade to help with farm work, but it is more and more common for children to go through high school or college, and this is expensive. The farm lighting plant, a water system for the farmhouse and numerous other improvements practically in the same class with the automobile, must be considered, so far as having the support of the entire family is concerned.

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What must the individual farmer spend for all his numerous purchases? Frequently, figures are printed which have been compiled as to the amount of money represented by the total crops produced, and which farmers will have to spend. Most farmers, however, who read such figures must wonder where their share of this sum is. How much money will a farmer be likely to receive from a corn-belt farm of 200 acres, representing a return much above that of the average farm? Corn is the principal cash crop in the corn-belt and the one returning the most profit. Assume that of the 200 acres, 100 acres are in corn. The average yield per acre does not quite reach 40 bu. even in the corn belt, but assuming 40 bu. per acre, the farmer would harvest 4000 bu. Until the war, corn has usually been about 70 cents per bu., but even during the last several years $1.50 per bu. at the farm is a very high estimate. This gives a gross return of $6,000. Suppose the other 100 acres is divided between oats and alfalfa. A fair average for the corn belt is 50 bu. of oats, and 50 acres at this rate would give 2500 bu. At 70 cents per bu., a liberal price, this would be $1,750. Fifty acres of alfalfa with a yield of 3 tons per acre would mean 150 tons, and at $10 per ton at the farm would give a gross return of $1,500. Figuring thus liberally, a 200-acre corn-belt farm could not be expected to produce more than a gross return of $9,250. If this were only a net amount there would be a stronger demand for tractors, even at high prices. Unfortunately, heavy costs such as labor, interest or rent, taxes, seed, overhead charges, etc., must be deducted. A low price for much of the present corn-belt land would be $200 per acre. At 7 per cent the interest on the land investment of a 200-acre farm would be $2,800. Of course, part of this interest would probably be available to the farmer, but a large percentage of farms have heavy mortgages. It would therefore be not at all too much to deduct $2,000 interest charge from the gross total. The work stock, according to the common estimate, would require 5 acres for each head. At least eight and perhaps ten work horses would be kept on a 200-acre farm today, but the former number, at $125 a year, would cost $1,000. Including board and other expenses another $1,000 will not cover the cost of hired labor. Overhead costs on buildings, fences, machinery,

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marketing and numerous other items of actually necessary operating expense will in almost every case reduce the net income to considerably below $2,000. This must provide part of the family's living expense, supply them with clothes, furnish the house and provide whatever recreation and luxuries they are to enjoy.

If an absolutely fair calculation is made, it is evident that a farm as large as 200 acres is not apt to return a sufficient profit to allow a farmer any great amount of money to invest in new machinery. The income from farms is, as a general rule, in direct proportion to their size for any given type. On corn-belt farms of 80 to 160 acres, the net returns are very low compared with those from most other kinds of business having anything like an equal investment of capital. Numerous investigations have shown without exception that the net income from farming is very small. In spite of all that may be said and believed regarding their enormous profits, farmers appear to be anything but satisfied with conditions as they have existed in the past and are found at present. Farmers show almost as much unrest and dissatisfaction today as labor unions show. On every hand they are endeavoring with more or less success to better their conditions and obtain a more adequate return for their labor. The Non-Partisan League movement in the Northwest is one evidence of this. The forming of numerous cooperative associations is further evidence, and to show the frame of mind of many farmers, attention may be called to the resolution recently passed by the Indiana Division of the Farmers' Educational and Cooperative Union, which called for a reduction of 25 per cent in the acreage planted to crops in 1920. The effect of carrying out such a resolution would be far-reaching, as is obvious. Nevertheless, it is quite likely that it will be carried out to a great extent. At any rate, reports already received as to the acreage of fall-sown grains in Illinois show a very heavy decrease, amounting to 50 per cent in some counties.

These conditions might at first glance seem to have little relation to the sale of tractors, but they do have a very strong influence. The farmer is in a peculiar position. He can always procure a fairly good living from his farm. If he and his family are willing to stint themselves somewhat in regard to articles which must be purchased, they can continue to exist even though the money returns from crops are extremely low.

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This fact has been largely responsible for so many farmers remaining in the business when they were not receiving an adequate return for their labor and invested capital. It enables them to reduce their tilled acreage and so cut down their expense for hired labor and operating cost, resulting in a public shortage of food supplies, which may still return them fully as much as a larger crop at lower prices. While thousands of farmers are in this frame of mind, it is useless to expect them to buy tractors. The real solution of their problem undoubtedly lies in increasing rather than decreasing their acreage, and in bringing about greater returns for their labor through the more efficient utilization of their labor by large labor-saving machines. Unfortunately, this is not being pointed out to them to any great extent.

It is impossible to calculate with any degree of accuracy the probable market for tractors today, without taking into consideration the economic problems with which farmers are confronted. The changed conditions brought about by the war have affected the farmer almost as much as the business man. The labor situation is perhaps even worse from the farmer's standpoint than from that of the industrial employer.

Human Versus Mechanical Labor

In two principal ways, farmers attempt to free themselves from the hired-help problem. One is to cut down the acreage being farmed and either engage in dairying to some extent or undertake the growing of crops which will provide employment for a large number of days each year, can be handled with little or no extra help and, because of the large amount of labor involved, return a greater amount of money per acre than crops usually grown by machinery. The other solution is to increase the size of the farm to permit utilization of the largest and most efficient labor-saving machinery, to operate on a sufficient scale to permit paying wages on a competitive basis with city industries and to provide enough work for both men and equipment to justify the necessary investment and overhead charges.

A number of companies and corporations have been formed within the past few years to carry on farming on a large and efficient scale, and this movement has

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doubtless just begun. Most of those engineered by experienced farmers seem to have proved profitable. Some have involved the growing of perishable truck crops and small fruits; others, general farming only. One of the largest and most recently formed is reported to be a $20,000,000 corporation to handle fruits only. This organization, like most of the others, expects to reduce the overhead charges through buying supplies and equipment in large lots, proper advertising of the product, ability to handle the entire marketing problem in a much better manner, using tractors and other large machines in all field work. Their financial resources will permit them to buy an adequate supply of the most modern machinery, and their large acreages will fully justify it. Great benefits have been predicted from these large farming schemes, and there are certainly enough possibilities in them to cause many more to be undertaken. One of them is of more than usual interest, because it was backed largely by representative capitalists and inaugurated as a war measure. It was planned on a magnificent scale, and was located on several thousand acres of Indian land. This section was recently stricken by a drought, and the wheat crop was a total failure. This experience should give business men a better conception of the risks involved in farming. It also shows that even though a farmer may make money some years, such profits must make up for the bad seasons which occur too frequently, even in desirable farming regions.

It has often been stated that there is no such thing as an average farm and it is just as true that there is no such thing as an average farmer. There are always great variations in the problems presented by any two farms. To classify them, the best that can be done is to place in a group those that are least dissimilar. In this great dissimilarity of farms and farmers lies another reason for the slow rate at which tractors have been bought. It does not follow that because one man on a 240-acre farm in the corn belt finds a tractor profitable, his neighbor with the same size farm will find a tractor equally profitable. The crop rotations on the two farms may be quite different. One farmer may like horses and raise colts for sale, while the other does not; one may be a good hand with machinery or may have a son or hired man who can operate a tractor satisfactorily, while the other may not; one may depend upon hired help, while the other may have boys of his own

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to assist him; one may have passed middle age and, like most elderly people, be rather averse to making any radical changes in his methods or equipment, while the other may be young, energetic and perfectly willing to try something new; one may have money laid aside either as the fruit of his own labor or through inheritance, while the other may be financially handicapped; and one may have excellent credit with his bankers and local business men, while the credit of the other may be poor. Thousands of other variations could be listed, each one of which actually exists in some instance. The size and type of farm are far from being the only factors which determine whether a tractor will be practical and whether it is likely to be used.

Equipment and Method Changes

Attempting to put a tractor on every farm above a certain acreage would be like trying to sell a motor truck or delivery car to every corner grocer in our cities. In Chicago, there are hundreds of small grocers who each maintain a horse and wagon for hauling goods from the wholesale house and delivering to customers. This does not mean that automobile delivery is not quicker, cheaper and more desirable in almost every way, but that the horse and wagon have in many cases been owned for a number of years, are still serviceable and meeting the requirements. Even if the storekeeper desired to sell his present outfit and purchase an automobile, he would find a very poor market for either the horse or wagon; hence, the new equipment would mean a considerable investment increase and an actual loss through the sacrificing of serviceable equipment. So long as he sees no probability of an increase in his business that the horse and wagon would be incapable of caring for, he is not likely to make a change. If his profits were more than necessary for the living expenses of himself and family he would probably spend the surplus for a passenger car rather than a new delivery vehicle. This is simply human nature and explains the enormous sale of automobiles to farmers, who do not buy tractors so freely.

The farmer is not alone in his inclination to continue using equipment which has proved adequate. It is nearly as difficult to sell new and improved machines to any other business man or manufacturer as to the

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farmer. It is only in newly built factories that the most improved machinery and equipment are found throughout. In older factories one is sure to find machines and equipment that are out-of-date and less efficient than other machines on the market. Hundreds of instances might be cited where large manufacturers are using methods and equipment which are out-of-date and much less efficient than later methods; but, so long as the old equipment continues fairly satisfactory, it is used because the loss through sacrificing it to buy the newest and most improved equipment will often more than offset the slightly greater labor cost in operating the out-of-date equipment. Furthermore, manufacturers often take the attitude that the newer and more improved machinery will probably become cheaper, or that further improvements may be made that will justify waiting. Farmers are fully as well justified in taking this course. Most farmers, although they may have made a fairly large investment, are receiving such small returns that they cannot afford to risk a large amount in an experiment. They like to be as nearly certain as possible that any new machine they buy will return a good profit.

It is but natural that farmers watch very closely how their neighbors' tractors are working out. The tractor manufacturers should answer very frankly, to themselves at least, what has been the result of such observations. It is true that a high percentage of tractors bought within the last several years have proved satisfactory to their users. Most owners will say that the machines have been profitable, but in order to get down to actual facts it is desirable that everyone realize just what these machines are actually doing for the men who own them. The farmer who is considering the purchase of a tractor should not be expected to take a particularly optimistic view and see things in a more attractive light than the facts actually warrant. He is rather critical of the performance of the machines, and the facts and figures as to what they have actually been doing certainly do not constitute a great incentive to hasten the farmer's purchase.

In advertising tractors and in attempting to emphasize their advantages over horses, the statement has been made repeatedly that the farm horse works on an average only about 100 days per year. This was intended to show that he was inefficient as a source of

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farm power and used only for field work, while the tractor could be used for belt work also. Figures obtained from tractor owners as to the number of days they use their machines for different kinds of work and as to the total number of days the tractor could be used each year, disclosed the fact that the tractor was generally used not to exceed 50 days per yr. and that on many types of farm it was used about half of this time at belt work. This was almost incredible to many people and its accuracy was questioned. Further investigation, however, showed that it was too high rather than too low an average.

Efforts to Increase Tractor Utilization

Some manufacturers, realizing that the tractor was being used so few days per year, that its work was largely limited to plowing and belt work and that horses were doing harrowing, disking, seeding and other operations following plowing, attempted to make the tractor more generally useful. They encouraged its use for practically all kinds of field operations, bringing out special harrows, disks, drills, harvesters and other machines to make the tractor more suitable for these operations. It was hoped that the perfecting of such machines for use with the tractor would result in its being used a much greater number of days annually.

Not many figures obtained within the past year are available to check up this expectation. Such as are available, however, do not indicate that the desired result has been accomplished. L. A. Reynoldson of the office of farm management of the Department of Agriculture, visited 141 corn-belt farms where tractors were used in the summer of 1919, and obtained from the operators the number of days the tractor had been used in the different kinds of farm operation and also the time that horses had been used. These data differed slightly from most that had been obtained previously. Instead of taking the total number of days on which the tractor had been used for belt or field work, the owners gave as nearly as possible the number of full days the tractor had been used. If a farmer used his tractor 2 hr. of 1 day each week to grind feed, instead of reporting the tractor used for 52 days for grinding feed, the figure would be 10.4 days. The investigation showed that tractors on the 141 farms visited were used only

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29 days each year on the average. Horses kept by these tractor owners decreased, on an average, two and one-half per farm, while the average size of farm had increased 24 acres. The horses remaining on these farms were used an average of 78 days per year. For the average farm, 565 days of horse labor was distributed among the various operations in order of their importance, rated on the number of days' labor involved, as follows:

	Days
Harvesting corn	100
Corn cultivating	84
Disking, harrowing, etc.	71
Road hauling	63
Hauling manure	48
Threshing	44
Plowing	33
Haying	29
Drilling	25
Cutting grain	24
Corn planting	16
Miscellaneous	28

The neighbors of these tractor owners would not receive much encouragement from such tractor performance unless their owners were getting much better yields than farmers using horses, or enjoying a greater profit by having their crops planted and harvested in season. These theoretical advantages, however, are not realized every season and the observer might not give them full benefit of their advantages along these lines.

Why do the farmers not make better use of their tractors? For an outfit costing $1,500 and used only 30 days each year, the interest charge alone would be about $3 per day, and depreciation, based upon a life of 10 yr., would be $5 per day. One must admit that a farmer has much better reason to put off purchasing a machine which he can use only 30 days each year than a manufacturer has for postponing the purchase of an improved machine that he can probably use every day. The average size of the farms on which the 141 tractors mentioned were used was 346 acres, which is considerably higher than the average for the country or even for the corn belt. As would be expected, the number of days the tractors were used annually increased almost directly with the size of the farm. On farms of 220 acres and less, the tractors were used only about 20 days on an average, while on 380 to 700-

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there must be enough acreage to keep it busy for a reasonable period each year. The number of days horses were used for various operations shows the need of developing more machines and attachments to make the tractor or truck suitable for the different kinds of work. For some, the motor cultivator will undoubtedly be used; for others, the truck will be more satisfactory than horses; for road hauling, hauling manure and probably some of the other work such as haying, corn harvesting, etc., the truck will have its place.

Granting that the sale of tractors has not been all that could be desired and that this condition can be improved upon, the principal question is how to overcome the obstacles which have interfered with the development of the business, so that the tractor will be generally adopted for farm work. First, the initial cost of a tractor must be such as to make it practicable for a business of the magnitude of a large percentage of farms. Second, it is obvious that what is commonly termed intensive cultivation, meaning the growing of crops by hand methods on small areas, does not tend to increase the sale of large machines of any kind, tractors included. But extensive farming, the raising of crops on a large scale with a minimum of human labor through the use of large labor-saving machines, does tend to encourage the use of all kinds of improved equipment, including tractors. Less consideration should be given to 10-acre farms and more to 1000-acre farms; the latter can use tractors to advantage; the former cannot. The problem will solve itself if things are allowed to take their own course, or the solution can be hastened by proper action. At present, farmers receive advice on practically every subject connected with farming except on the use of labor-saving machines. All kinds of experiments and investigations are being carried on in the breeding of live stock and better crops; likewise, experiments in the building up and maintenance of soil fertility are being carried on in great number. Such detailed information can be obtained by any farmer who wishes it, but regarding information as to the best crop rotation and acreage to make use of a tractor efficiently, little is available.

It is unreasonable to expect each individual farmer to be capable of working out an organization and crop

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rotation for his farm which should make it possible and practicable for him to use a tractor. He is not much more likely to do this than he is to breed a better variety of wheat by hybridizing. Some individuals will solve their own problems of this kind. The large percentage of tractor owners who enlarge their farms and increase their returns by a better farm organization on an extensive scale are ample proof of this. What is needed is to ascertain just exactly how these successful users have reorganized, and to pass this information on to other farmers. Organizations are now teaching farmers how to treat their hogs for cholera, how to fumigate seed and inoculate soil, and are giving other information which adds to general prosperity. The farmer should be told how to change over from a small and inefficient plant where human labor is being wasted, to a larger and efficient food-production organization, on which he can practise the same principles of quantity production as are practised by large manufacturers today. Farming needs to be put on a quantity production basis fully as much as does any other industry for the good of the individual farmer and of the country as a whole.

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PENNSYLVANIA SECTION PAPERS

FACTORS INVOLVED IN HIGH AIRPLANE SPEED AT GREAT ALTITUDES

By Commander H C Richardson,[1] U S N

The development of the supercharger for aircraft engines has led to the possibility of hitherto unheard-of speed of transportation. An analysis of a definite case is presented to show the different aspects of the problem in a practical form, with a view toward determining what can reasonably be expected. An attempt is also made to arrive at a knowledge of the elements involved whose improvement will effect the greatest gain. The supercharger overcomes the deficiency of the ordinary gas engine's serious loss of power at great altitudes, due to its inability to obtain sufficient oxygen for the combustion of a normal charge of gas which, in an engine of conventional design, is essential to the development of its maximum output. The required and available horsepowers of the airplane itself are considered mathematically, airplane propellers and their characteristics are discussed, the climbing and flying speeds of an airplane having a supercharged engine are presented and the miscellaneous factors involved are enumerated.

The development of the supercharger for aircraft engines has led to the possibility of hitherto unheard-of speed of transportation. Many predictions are extravagant, at least for the present state of the art, so it is attempted in the following analysis of a definite case to present the different aspects of the problem in practical form, with a view to determining what can reasonably be expected. The attempt is also made to arrive at a knowledge of those elements involved whose improvement will effect the greatest gain.

As is well known, the ordinary gas engine suffers a serious loss of power at great altitudes, due to its inability to obtain sufficient oxygen for the combustion of a normal charge of gas which, in an engine of conven-

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tional design, is essential to the development of its maximum output. The supercharger overcomes this deficiency by providing a fuel mixture of normal proportions and density, practically eliminating the loss of power otherwise resulting from the rarefied atmosphere at great altitudes. To introduce exact corrections of the power available at different altitudes would require the introduction of data and refinements which are not essential to this investigation. It is therefore assumed that the supercharger is already in practical form and can be applied so as to furnish the same power output, unaffected at attainable altitudes. This requires also that the reduction of the heat-dispelling capacity of the radiating system be partly compensated by the low temperatures at great altitudes and partly by its excess capacity over that usually provided at sea level. Granting this, we may then assume as a first premise that the brake-horsepower characteristics based upon the performance at sea level can be accepted for this investigation as applying at great altitudes. This premise is substantially correct, and is essential for the following application to the problem.

Required and Available Horsepower

Let us now consider the airplane itself. We have first to determine the horsepower required, and the influence of air density upon this factor; second, we must determine the horsepower available. This latter depends primarily upon the brake-horsepower characteristics of the engine employed, and secondarily upon the means of applying the engine power to propulsion, that is, to the propellers. Propulsion is the most interesting and important factor, as will be seen later.

The influence of altitude and air density upon the horsepower required is readily determined by a brief analysis of the fundamental equations of flight. In this analysis the notation given at the top of page 1017 is employed.

$$D = K_x \triangle S V^2$$

$$EHP = \frac{TV}{375} \qquad (1)$$

$$H = K_h \triangle S V^2$$

$$L = K_y \triangle S V^2$$

$$T = D + H$$

$$V^2 = \frac{W}{K_y \triangle S}$$

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NOTATION EMPLOYED

D = the drift
EHP = the effective horsepower required
H = the head resistance
$K_h = 0.003$
K_x = the drift factor of the wing
K_y = the lift factor of the wing
L = the lift
S = the area of lifting surfaces
s = the parasite resistance area
T = the thrust in pounds
V = the velocity of flight in miles per hour
W = the weight of the airplane in pounds
Δ = the air-density factor

By substitution equation (1) becomes

$$EHP = \frac{\Delta W^{3/2}}{375(K_y \Delta S)^{1/2}} \times K_x S \cdot K_h s$$

$$= \frac{W^{3/2}}{(K_y S)^{1/2}} \times \frac{K_x S \cdot K_h s}{375 \Delta^{1/2}}$$

Introducing the subscript o for standard conditions at sea level, and the subscript a for standard conditions at the altitude A, we obtain

$$EHP_o = \frac{W_o^{3/2}}{(K_{yo} S_o)^{1/2}} \times \frac{K_{xo} S_o \cdot K_{ho} s_o}{375 \Delta_o^{1/2}}, \text{ and}$$

$$EHP_a = \frac{W_a^{3/2}}{(K_{ya} S_a)^{1/2}} \times \frac{K_{xa} S_a \cdot K_{ha} s_a}{375 \Delta_a^{1/2}}$$

$$V_o^2 = \frac{W_o}{K_{yo} \Delta_o S_o}, \text{ and}$$

$$V_a^2 = \frac{W_a}{K_{ya} \Delta_a S_a}$$

The variation between W_o and W_a at any altitude at present attainable is negligible; they are therefore considered equal as well as the corresponding values of K_h, K_x, K_y, S and s.

If we therefore confine the comparison to a fixed angle of attack we find that

$$\frac{EHP_a}{EHP_o} = \left(\frac{\Delta_o}{\Delta_a}\right)^{1/2}, \text{ but}$$

$$\frac{V_a}{V_o} = \left(\frac{\Delta_o}{\Delta_a}\right)^{1/2}, \text{ hence}$$

$$\frac{EHP_a}{EHP_o} = \frac{V_a}{V_o} \qquad (2)$$

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Equation (2) derived from the fundamental equations, is very interesting. Translated, it means that as the air density decreases the velocity required for sustentation increases with the square root of the ratio of the air density at any altitude to the air density at the ground. What is still more interesting is that the effective horsepower required increases in the same ratio. In other words, the effective horsepower required increases in direct proportion to the increase in speed, *if the angle of attack is unchanged.*

As the development of equation (2) includes the total effective horsepower required to overcome the combined wing and parasite resistances, it permits the determination of the effective horsepower required at any altitude in a direct and simple manner, either graphically or by computation. The only data required are the effective-horsepower-required curve for the airplane at sea level, and the ratio of the air density at the required altitude to the air density at the ground. For example, suppose that at sea level, at a 4-deg. angle of attack, 150 e.hp. is required at 90 m.p.h. It is required to determine the effective horsepower and V at an altitude where the air density is 0.5 that at sea level.

By computation,

$$\frac{\Delta_o}{\Delta_a} = 2, \text{ hence}$$

$$\begin{aligned} EHP_a &= 150 \times \sqrt{2} \\ &= 150 \times 1.414 \\ &= 212, \text{ and} \end{aligned}$$

$$\begin{aligned} V_a &= 90 \times \sqrt{2} \\ &= 90 \times 1.414 \\ &= 127. \end{aligned}$$

Graphically, the new spot on the effective-horsepower curve for a 4-deg. angle of attack will be found on a vector from the origin through the original 4-deg. spot at a point distant from the origin 1.414 times the distance of the original spot, as in Fig. 1.

The diagonals or vectors may be measured on any convenient scale of length. Fig. 2 illustrates the effective-horsepower curve of an actual airplane of clean design equipped with a 400-b.hp. engine. At the surface, with a propeller of 75 per cent efficiency, this plane indicates 154 m.p.h. By the use of the supercharger, if the propeller efficiency remains constant at 75 per cent and the propeller permitted the engine to develop its full

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number of revolutions per minute, this plane should be capable of making 171 m.p.h. at 10,000 ft., 190 m.p.h. at 20,000 ft., 208 m.p.h. at 30,000 ft. and 233 m.p.h. at 40,000-ft. altitude.

No simple propeller is capable of such performance. If the engine develops its full power at the different altitudes, the propeller working in the rarer atmosphere is unable to absorb the horsepower output at the same number of revolutions per minute and further, the thrust and the propeller efficiency are both affected by the changes in the air density and the speed of advance necessary to sustentation. It therefore becomes necessary to adopt some device which will permit the power to be absorbed at not more than a certain maximum number of revolutions per minute of the engine. Two methods are available; one, already in use, is the variable-pitch

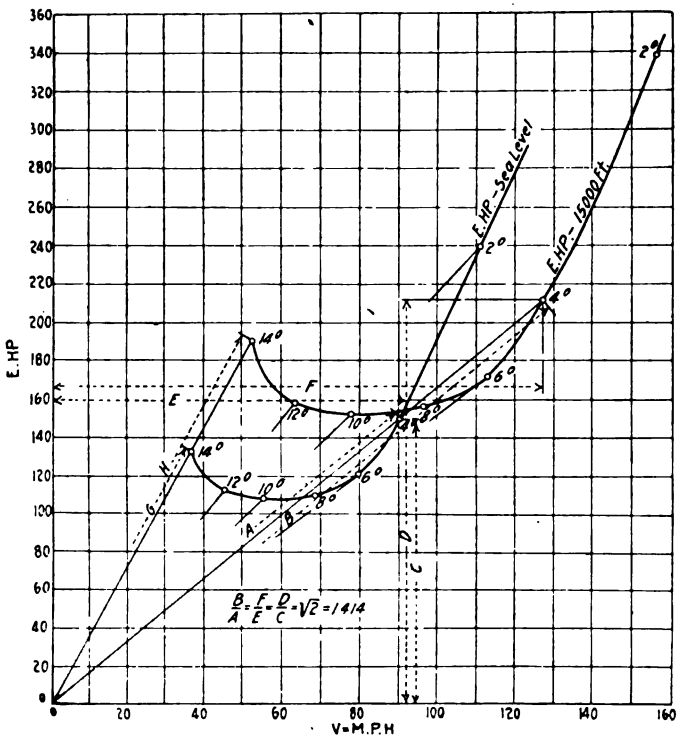

FIG. 1

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propeller; the other requires the introduction of a variable-speed device or shift gears. Another device which is purely a subterfuge is to over-propeller the airplane at the ground surface, but this seriously handicaps surface performance and climbing power.

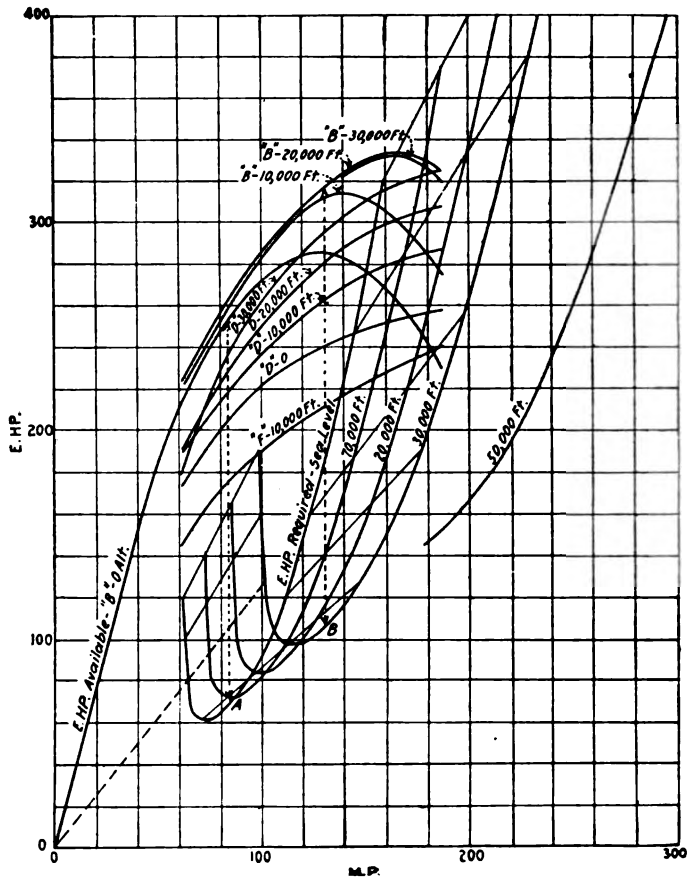

FIG. 2

AIRPLANE PROPELLERS

To illustrate the importance of the propeller side of the problem I have chosen a definite propeller of the variable-pitch type for which data are available. This is the one for which data are given in report No. 30 on

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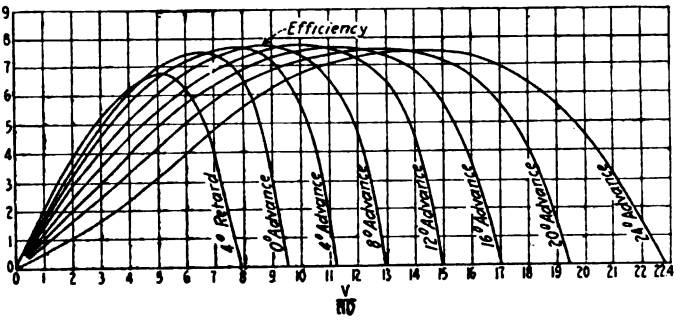

FIG. 3

Experimental Research on Air Propellers, Part II of the Fourth Annual Report of the National Advisory Committee for Aeronautics, 1919. These data are based upon investigations laid out by Dr. W. F. Durand at the wind tunnel at the Leland Stanford University, and executed under the direct charge of Prof. E. P. Lesley. The characteristics of this propeller are given in Figs. 3 and 4. These figures are based upon the metric system, the French unit of power being about 0.986 of our standard.

The brake-horsepower characteristic for the engine used

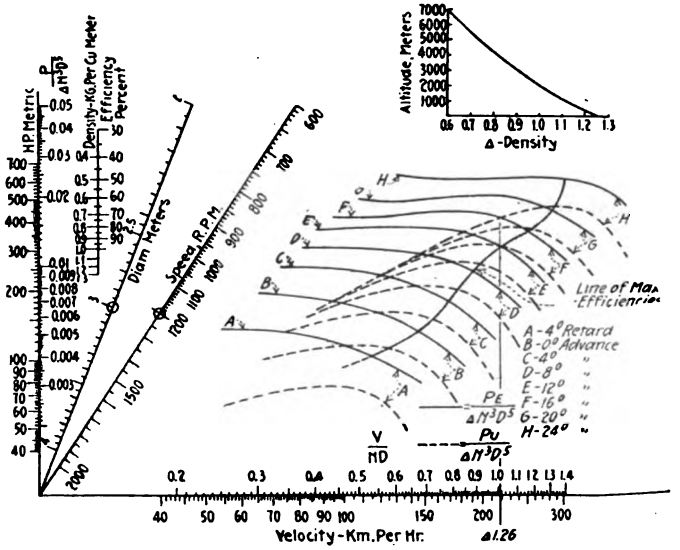

FIG. 4

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in the computation is plotted in Fig. 5, in which are shown the revolutions per minute and brake-horsepower for both the French and United States units. Applying the characteristic to the logarithmic diagrams of Fig. 4, the performance for each setting *B*, *C*, *D*, *F* and *H*, of a 10-ft. variable-pitch propeller has been determined for different altitudes and velocities of advance. The results are presented in Table 1. All the data given in the table have been graphically determined and are subject to the errors of such a method. The resultant data are reasonably accurate and consistent. Their analyses show the results to be expected from the use of this type of propeller in conjunction with an engine equipped with a supercharger. So many variables are involved that it is difficult to arrive at a comprehensive plot.

Fig. 6 is based upon the altitude in meters, showing the effective horsepower available for each setting, with a variation in the speed of advance of 100, 150, 200 and 300 km. per hour. It gives a direct insight to the influence of altitude and speed of advance upon the performance of the engine as restricted by the propeller action. The revolutions per minute and efficiency are indicated for each spot. It is interesting to trace their variations. From the plots of Fig. 6 cross curves are taken and shown on Fig. 2. From an inspection of the curves of Figs. 2 and 6 it appears, as was to be expected, that the propeller can only absorb the horsepower developed by speeding up in the thinner atmosphere, or by being twisted so that its pitch is increased.

It is regretted that the Durand data do not permit the graphical application beyond a speed of 300 km. per hour, although even in this range it appears that the normal form of the propeller develops increased power up to about 170 m.p.h., but it does so by permitting the engine, whose normal speed is 1800 r.p.m., to run up to 2100 r.p.m. Even the *C* setting runs it up to 2000 r.p.m. at this speed of advance. The higher pitches help to hold down the number of revolutions per minute as the speed of advance and the altitude increase. The *F* setting permits 191 m.p.h. to be obtained at 1540 r.p.m., but the reduced number of revolutions per minute, together with the decreased efficiency, reduce the effective horsepower to 285 at 30,000-ft. altitude. Beyond this point, although the number of revolutions per minute rises rapidly the efficiency falls rapidly, so that the maximum effective horsepower available is soon attained. An interesting

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interpretation of these conditions is that the variable-pitch propeller can be used as a governor on wide-open throttle to keep the engine speed from becoming excessive and that, to obtain the best results, departures from the normal forms should only be made for this purpose.

Climbing and Flying Speeds

A remarkable indication in this respect is that the climbing rate with a supercharged engine, on an air-

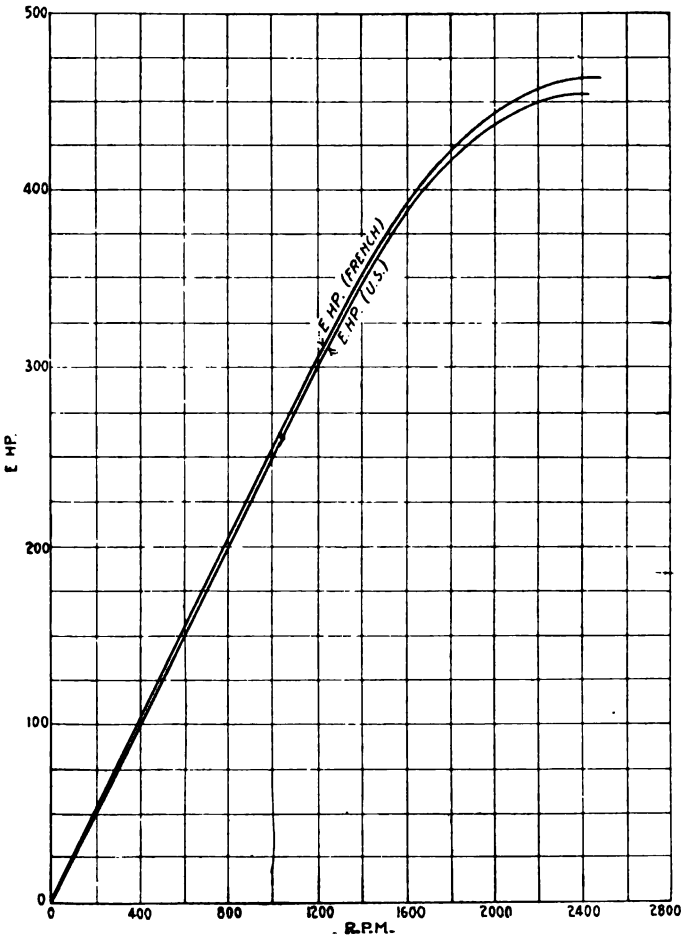

Fig. 5

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TABLE I.—PROPELLER DATA

Altitude		Velocity		B				C				D				F				H			
m.	ft.	km. per hr.	m.p.h.	Speed, r.p.m.	Propeller Efficiency, per cent	B.hpr.	E.hpr.	E.hps.	Speed, r.p.m.	Propeller Efficiency, per cent	B.hpr.	E.hpr.	E.hps.	Speed, r.p.m.	Propeller Efficiency, per cent	B.hpr.	E.hpr.	E.hps.	Speed, r.p.m.	Propeller Efficiency, per cent	B.hpr.	E.hpr.	E.hps.	Speed, r.p.m.	Propeller Efficiency, per cent	B.hpr.	E.hpr.	E.hps.
0	0	100	62	1330	63	335	211	214	1150	65	293	191	194	1040	65	265	172	174	870	62	222	138	140	730	55	186	102	103
		150	93	1430	72	362	261	264	1240	75	313	235	238	1020	75	287	215	218	870	74	222	164	167	720	71	182	129	131
		200	124	1570	73	385	281	285	1370	77	342	263	267	1190	78	302	235	238	960	76	243	185	188	730	75	186	140	142
		300	186	1910	53	432	228	231	1660	56	382	214	217	1430	56	362	203	206	1150	64	293	188	..	850	46	217	100	101
2,000	6,560	100	62	1460	60	362	217	220	1270	61	337	206	209	1150	60	293	176	178	990	57	250	143	146	812	49	206	101	102
		150	93	1560	70	382	267	270	1350	72	339	244	247	1190	63	302	220	223	965	71	245	174	177	815	66	208	137	139
		200	124	1680	75	403	302	306	1475	78	363	283	287	1290	77	323	248	251	1030	75	262	196	199	815	74	208	154	156
		300	186	1975	57	440	251	249	1700	62	370	230	233	1510	67	372	249	252	1205	69	305	210	213	910	72	231	166	168
4,300	14,100	100	62	1605	56	391	219	222	1410	57	330	188	191	1290	58	323	193	196	1115	51	283	144	146	900	42	228	96	97
		150	93	1690	67	404	271	275	1465	70	363	254	258	1310	70	330	231	234	1085	68	275	187	190	912	63	232	146	148
		200	124	1800	73	417	305	309	1570	75	382	286	289	1390	76	347	264	268	1110	75	282	212	215	912	72	232	160	163
		300	186	2100	72	450	324	320	1805	71	419	297	304	1600	71	390	273	277	1290	75	323	242	245	990	70	250	175	178
7,150	23,450	100	62	1800	51	417	213	216	1600	52	390	203	206	1470	50	365	183	186	1275	43	321	138	140	1005	35	255	90	91
		150	93	1870	64	427	274	271	1630	66	395	261	265	1485	66	367	242	245	1250	63	315	198	201	1060	56	269	151	153
		200	124	1970	72	440	316	312	1715	74	407	301	305	1530	73	376	275	279	1240	72	313	225	228	1050	68	267	181	184
		300	186	2300	71	460	326	322	1960	73	..	..	..	1710	76	406	308	312	1400	77	349	269	272	1080	75	275	206	209
9,000	29,500	100	63	1930	50	435	217	215	1712	50	409	204	207	1600	47	390	183	186	1370	39	343	134	136	1010	30	212	82	83
		150	93	1990	63	442	278	271	1750	65	412	268	272	1600	63	390	246	249	1370	59	343	202	205	1150	51	293	150	152
		200	124	2080	60	449	270	268	1810	70	419	293	297	1650	72	398	287	291	1350	70	339	237	240	1150	65	293	190	193
		300	186	2200	71	456	324	320	2140	73	..	..	..	1800	77	417	322	326	1460	76	362	275	279	1160	71	292	207	210
11,250	36,900	100	62	2075	47	448	211	209	1950	44	..	..	..	1780	32	415	150	152	1500	34	370	126	128	1150	26	293	76	77
		150	93	2150	60	454	272	276	..	....	..	..	..	1760	59	412	243	246	1550	55	380	204	212	1280	46	322	148	150
		200	124	2240	68	457	311	307	..	....	..	..	..	1800	69	417	288	292	1510	66	372	245	248	1300	60	326	196	199
		300	186	2470	75	460	345	341	..	....	..	..	..	1950	76	.	..		1580	75	387	290	294	1300	73	326	238	241

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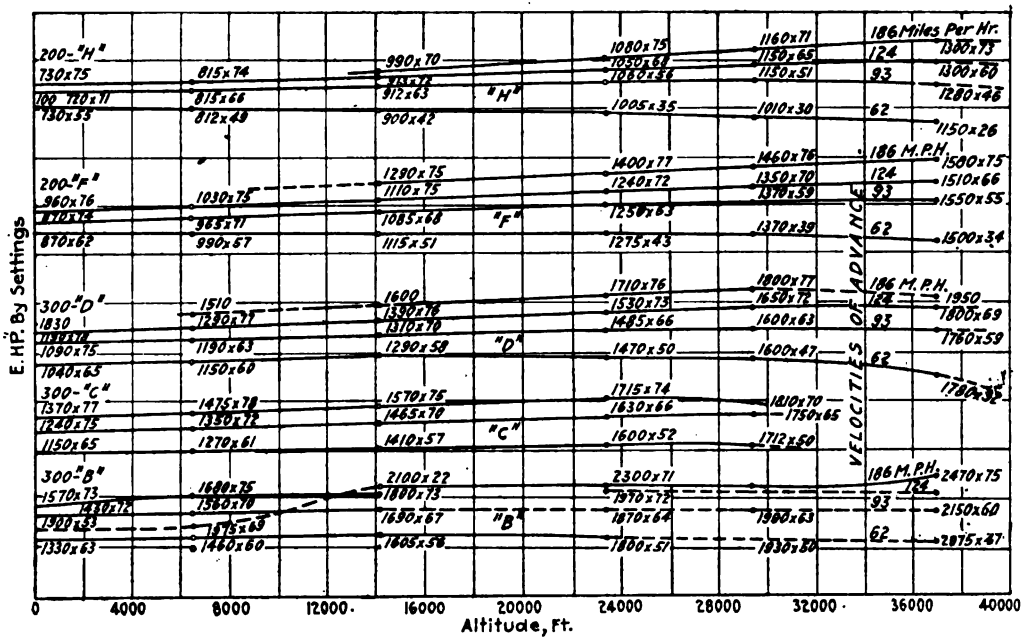
E.HP. By Settings
VELOCITIES OF ADVANCE
186 Miles Per Hr.
124
93
62
186 M.P.H.
124
93
62
186 M.P.H.
124
93
62
186 M.P.H.
124
93
62
200-"H"
730x75
100 780x11
730x53
815x74
815x66
812x49
990x70
912x63
900x42
"H"
1080x75
1050x64
1060x36
1005x35
1160x71
1150x65
1130x51
1010x30
1300x73
1300x80
1280x48
1150x26
200-"F"
960x76
870x62
1030x75
985x71
990x57
1290x75
1110x75
1085x68
1115x51
"F"
1400x77
1240x72
1250x63
1275x43
1460x76
1350x70
1370x59
1370x39
1500x75
1510x66
1550x55
1500x34
300-"D"
1830
1090x75
1040x65
1510
1290x71
1190x63
1150x60
1600
1390x76
1310x70
1290x58
"D"
1710x76
1530x75
1485x66
1470x50
1800x77
1650x72
1600x63
1600x47
1950
1800x69
1760x59
1780x35
300-"C"
1370x77
1240x75
1150x65
1475x70
1350x72
1270x61
1570x75
1485x70
1410x57
"C"
1715x74
1630x66
1600x52
1810x70
1750x65
1712x50
300-"B"
1570x73
1920x83
1330x63
1600x75
1560x70
1460x60
2100x22
1800x73
1650x67
1605x58
"B"
2300x71
1970x72
1870x64
1800x57
1900x83
1830x80
2470x75
2150x60
2075x87
0
4000
8000
12000
16000
20000
24000
28000
32000
36000
40000
Altitude, Ft.

FIG. 6

plane of the type chosen for illustration, should improve with altitude. This is indicated by the reserve horsepower shown at the points *A* and *B*. Thus, at *A* the reserve power is about 182 hp., and at *B* it is 218 hp., or a 20 per cent gain in the rate of elevation, while the best speed for climbing increases from 84 to 130 m.p.h. Another interesting indication is that, with the propeller selected, the maximum speed at the ground surface should be about 150 m.p.h., while at 30,000-ft. altitude this speed should increase to more than 200 m.p.h.

The suggestion of variable-speed gearing, or shift gearing to hold the normal form of blade to a proper *V/ND* ratio while still absorbing full engine power, naturally develops. Particularly when we note that even at 186 m.p.h. all settings of the variable-pitch propeller have passed their peaks of efficiency. By the adoption of these means, such an airplane as was assumed in the example might make 260 m.p.h. at about 50,000-ft. altitude. Travelling east at 30,000-ft. altitude, there is stated to be an average wind of over 100 m.p.h. We may thus reasonably predict 350 m.p.h. at an altitude of 50,000 ft., which would make the distance from New York to London or Paris a 10-hr. trip.

Miscellaneous Factors

Let us now consider a few other factors. In such thin atmosphere the effects of disturbance upon the airplane are greatly augmented and the finest type of instruments adjusted to work at low temperatures and pressures must be used. The ordinary magnetic compass goes wild if turning is present and loses accuracy if the plane is inclined. The inclinometer also fails to indicate true levels when turning and, as at such altitudes the surface is indistinct or often obscured by clouds, surface indications can no longer be depended upon to determine the true altitude of the plane and drift observation of the surface, to determine whether or not the true course is being followed, becomes almost impracticable.

The following instrument equipment is indicated as being necessary:

A turning indicator with positive action
A highly sensitive compass
A sensitive inclinometer
A drift meter

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A radio compass
The usual instruments showing performance of the power plant
Special oxygen equipment and clothing for the pilot and passengers
Increased cooling capacity for the radiating system

The useful load will then be reduced by the extra equipment, additional radiating capacity, supercharger

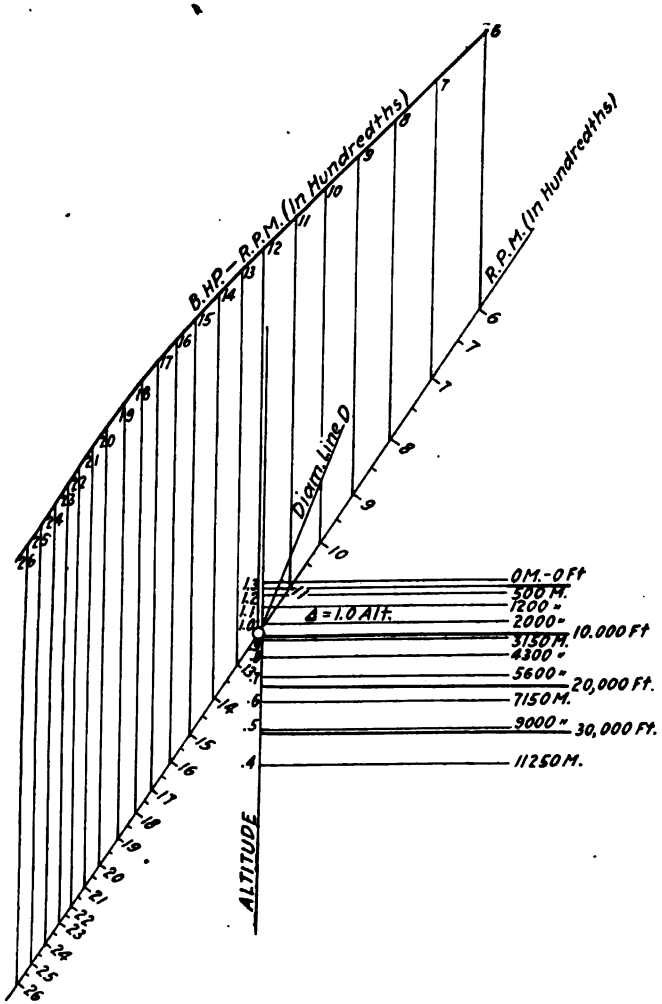

FIG. 7

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gear and the increased weight of a variable-pitch propeller, or of change gears, if used. Further, not everyone is fitted to exist and act normally under the conditions that will be encountered.

Aside from the advantages to be gained from the use of the supercharger and the variable-pitch propeller, as outlined, all the advantages of a reduction in horsepower at the surface by the elimination of resistance become augmented at great altitudes, as indicated by the law of increased power required. An interesting point, almost forgotten in the desire to demonstrate possibilities at high speed, is the modification of the cruising speed. Thus, at sea level, the best cruising speed would be about 75 m.p.h.; at 30,000-ft. altitude it would increase to 130 m.p.h. The effective horsepower required would, however, increase from 62 to 106, the net effect being that the cruising radius is substantially unchanged.

We thus arrive at the conclusions that by increased altitude we may expect a greatly increased speed, but can hardly hope to increase the radius of action. In fact, unless the wind at great altitudes favors the direction we desire to take, we shall probably lose because, while climbing, we must lift a load of gas and oil, thus expending energy to lift a weight that will be consumed in flight, and which will not be available to return the equivalent energy in descent. It is not so remarkable that this is true, for it has already been proved for the ordinary type of engine. The reason is obvious. It is that the effective horsepower required for flight depends upon the airplane, and the brake horsepower required depends on the airplane's effective horsepower and the propeller efficiency. Under these conditions the supercharger has practically no influence.

It appears that the variable-pitch propeller is principally useful as a governor at high speed. If it were not for limits to the number of revolutions per minute, the basic form of propeller carefully selected would give greater effective horsepower than the modifications available in the variable-pitch propeller. It also appears more than probable that shift gears would permit a most efficient combination for a specific case. Whether or not they should be adopted will depend upon the possibility of developing and applying such gears without such an increase of weight as would make the net result a handicap instead of an asset.

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THE DISCUSSION

MR. STERNBERG:—When Major Schroeder was up about 36,000 ft. he lost consciousness and fell. Are there any data on how many seconds away from the earth he was when he regained consciousness?

COMMANDER H. C. RICHARDSON:—He fell about 5 miles at the rate of 300 m.p.h., and he became conscious at an altitude of about 300 ft., I believe, so he must have been only a few seconds distant from the earth. He managed to pry his eyes open and saw that the altimeter showed 300 ft. It was of the repeating type. At that time he thought he was up 2300 ft. But he was able to recognize his position and put on power. He climbed to about 2800 ft. Then he concluded he might become unconscious again, and so he steered for clear country. In his climb for 2800 ft. he was able to get away from a field on which he did not wish to land. He wished to reach McCook field, but when he attained 2800 ft. he found his eyes were shut. He pried them open again and was able to reach McCook field and make a landing before he finally collapsed.

To give an idea of what might be endured by those who wish to go to great altitudes, I understand that his heart expanded 9 in. and that his ribs were pushed out by his heart. Just what other physical effects he had I am not sure. I know that when I saw Major Schroeder recently he was recovering fairly rapidly. He had to wear goggles but could see and appeared to be fairly normal, except that he did not dare to subject himself to any unusual excitement.

G. A. RICHARDSON:—The use of a variable-pitch propeller was mentioned. Is there any inherent weakness in the use of the propeller under the conditions that would have to be met as compared with gearing? What is the general design of propellers in which it is possible to change the pitch? Have they any mechanical weakness?

COMMANDER RICHARDSON:—No, there is no mechanical weakness in the variable-pitch design. The design is not clean all the way to the hub, as it would be in a good propeller, and to introduce the variable-pitch devices and control the variable-pitch while the engine is in motion there must be additional weight over what would be required in a normal propeller. Also, when the pitch is changed, the efficiency is somewhat less than given by a properly-designed propeller for a specific condition. But,

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as was shown in the efficiency curves, the efficiency holds high and fairly uniform as the pitch is changed, provided the velocity of advance is increased in proper proportion.

CHAIRMAN A. K. BRUMBAUGH:—Has anyone actually constructed such a gear set?

COMMANDER RICHARDSON:—Not for airplane use. The variable-pitch propeller is now designed so that it will work negatively and bring the airplane to a stop quickly.

J. A. ANGLADA:—What are the possibilities of helicopters?

HELICOPTERS

COMMANDER RICHARDSON:—The helicopter can be built and can probably carry a crew. It can be divided into several units, so that the torque will not cause difficulties, and it will lift straight along the propeller axis. That will not necessarily be vertical. If I were less sure of that, I would have more faith in the helicopter. All that it will do is to pull on the center of gravity along the line of the propeller axis. If the problem of stability can be solved, and probably it can be by the introduction of control surfaces in the propeller blast, so that the machine will not roll over like an umbrella when the wind hits it, the helicopter may be possible. I understand that designs have been worked out both in this country and in France, and each of the two designs probably has considerable merit. They amount to building the helicopter propeller so large that it is practically a pair of airplanes running around a vertical shaft.

The other difficulty with a helicopter is in regard to what will happen when the power fails. Most inventors advise carrying one or two extra powerplants. It may be possible to make the helicopter blades of such a section that they can be reversed, so that when the machine starts to fall the same result can practically be brought about that obtains with an airplane when it goes into gliding, and that the helicopter's own potential can be used to produce the propelling force. That will require putting a brake on the propeller-shaft. If the gliding condition can be produced with those blades, we will get closer to a solution with the helicopter; it does not appear impossible. The lifting power is certainly available, but unless an approach is made to what really amounts to a tentative airplane, one of the principal advantages that the airplane has will be lost. With a helicopter, to lift

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1 lb. a 1-lb. thrust must be developed. With a good airplane, only 0.1-lb. thrust is required to lift 1 lb. The airplane itself converts the propeller thrust into a much greater lift. When the helicopter meets these conditions it will begin to enter a possible field. The main difficulties are its instability and what will happen when it must descend without power.

Variable-Diameter Propeller

G. C. Loening:—Is there anything in the variation of the diameter of the propeller that might aid in overcoming the difficulties? Would it be possible to carry along two propellers and vary their diameter by shifting gears, for example?

Commander Richardson:—That should be a very interesting development. If the diameter should be increased, the same pitch might be retained and still hold the engine down. The propeller would again be acting as the governor, which is the function which it must perform when great altitudes are attained and the engine power is maintained. Sperry uses a device similar to that in the driving of his electric generators. He has blades which have springs in them to modify the propeller action, acting as a windmill instead of a propeller. The springs in the blades merely vary the pitch and not the diameter of the propeller, so that he practically has a constant-speed generator and can control the voltage of the generator at different speeds of the airplane. It is not a variable-diameter propeller. I have never heard of a variable-diameter propeller, but it appears to be a possibility.

Mr. Cook:—Does not a propeller with a heavy pitch have a tendency to churn the air instead of pushing it backward?

Commander Richardson:—It does if the machine is not proceeding at the proper speed. That is, if the pitch is too high for the speed of advance. The pitch of the blade of the propeller ought to be suited to the speed of advance. Most of the propellers work well at a speed of advance in which the pitch speed is about 25 per cent greater than the speed of advance. With a high-pitch propeller working under those conditions, I think there will be no more churning than with another propeller working at probably higher revolutions and lower pitch. The churning comes about when the proper speed of ad-

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vance relative to the pitch is not secured. I refer to geometrical pitch. The pitch of a propeller is a variable quantity which no one can really measure.

C. D. LEFEVRE:—What is the cause of the high velocity of the wind at great altitudes, from west to east?

COMMANDER RICHARDSON:—I do not know.

MR. LEFEVRE:—Would the revolution of the earth ever have any effect on the wind velocity? If so, would it not cause a wind from the east rather than from the west?

COMMANDER RICHARDSON:—It would seem so, following the analogy of the trade wind. It may be a counter-trade wind. The regular trade winds come from the northeast. They are blowing to the west; at their terminus they become heated and start back, and it may be that it is a counter-trade-wind effect; but if that were the case we would expect to have a southerly component wind. I understand that at Dayton the wind has been found coming from slightly north of west, which seems to disprove that idea. I understand that observations have been made at the equator, as far north as 45 deg. of latitude and still farther; and that, in general, at an altitude of about 30,000 ft. the wind is still westerly, even though at the equator or up to a latitude of 45 deg. That makes the condition interesting and difficult to account for, and I have not heard of any real explanation. But as the facts given us by people who have been there are in general accord, we must believe and find the reason.

LIEUT. RALPH S. BARNABY:—Are there any accurate data on the horsepower absorbed in pushing an airplane equipped with a supercharger through the air?

COMMANDER RICHARDSON:—I have seen no such data. The supercharger gives a somewhat bulkier nose to the machine. The horsepower that is absorbed by the supercharger itself apparently does not affect the horsepower available from the engine, probably because the amount of supercharging is not controlled automatically, but by hand. The supercharger is used to any degree that is desired.

LIEUTENANT BARNABY:—From photographs of the installations that have been made, it appears that the head resistance is increased greatly by the addition of the supercharger.

COMMANDER RICHARDSON:—That is very likely true. All such things must be considered. When a supercharger and a propeller are installed we do not get something for nothing, the machine must carry that weight

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instead of gasoline and, while we may expect to increase the radius of action, the way to get that is to revise the design of the airplane rather than to change the design of the engine. There is no need to go to great altitude to obtain the radius of action. If we wish to arrive quickly there is an advantage, but with the least amount of gasoline there is no advantage in going up. Besides, in going up the gasoline is lifted to a great altitude and its weight is reduced so that it is not available to return its value when coming into the glide.

LIEUTENANT BARNABY:—If the weight of the supercharger were put into the engine, could not sufficient additional power be obtained so that all the power needed for the altitude would be obtained? For instance, the Curtiss triplane manages to climb high without any supercharger because it is a much cleaner design and the engine probably develops somewhat more power. It appears that by putting the weight of that supercharger into the engine it would be found that the design had a somewhat higher power on the ground and that the same effect would be obtained at great altitude.

COMMANDER RICHARDSON:—The principal reason some excellent results were obtained without a supercharger in that case is that the plane was very much over-propellered at ground level, so that at great altitudes the propeller did not permit the engine to race, but did permit it to develop all the power possible without running at an abnormal number of revolutions per minute.

LIEUTENANT BARNABY:—By installing a variable-pitch propeller without the supercharger on the same airplane, they could get the desired climb near the ground, by reducing the pitch, and could then adjust the propeller so that they could increase the speed as they went up.

COMMANDER RICHARDSON:—In his great-altitude test Major Schroeder was not attempting to attain the maximum speed obtainable but altitude. He was therefore working at a point on the horsepower curve where he had reserve horsepower and he did not meet the limit until he reached the maximum of his altitude. If he had attempted to go at higher speeds up there, he might not have done so well. The supercharger certainly would have had probably twice the brake horsepower available that he had, because he did not have the density of charge, and he could not get the horsepower.

LIEUTENANT BARNABY:—He had no way to absorb that extra power except by speeding up?

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COMMANDER RICHARDSON:—That was the only way. Under those conditions, I believe that the horsepower reaches about the 1.1 power of the density ratio.

MARINE HEAVY-OIL ENGINE INSTALLATION PRACTICE AND DEVELOPMENT POSSIBILITIES

BY HUBERT C VERHEY[1]

The undisputed economy of the Diesel-type engine using heavy fuel oil is recognized, as no other power-generating unit of today shows better thermal efficiency. It is the result of the direct application of fuel in working cylinders. Transmission processes, such as the burning of fuel under a boiler to produce a working agent which must be carried to the prime mover, are less economical. The various factors which enter into a comparison between steam and heavy-oil installations are illustrated.

The subject is treated in a more or less elementary manner. The diagrams and sketches are intended to explain the working principles of such examples of two and four-cycle engines as are now in actual operation in cargo ships, these being of the single-acting type. Double-acting and opposed-piston-type engines have been built and are being tried out.

The working processes of two-cycle and four-cycle engines are illustrated and described in some detail, inclusive of critical comment. The working scheme of a four-cycle single-acting marine Diesel engine, shown diagrammatically, is followed through, covering the subjects of starting air, compression, fuel oil, lubricating oil, crankcase and fuel-valve design, valve gears and reversing, fuel pumps and Diesel-engine-driven auxiliaries on modern ships. A lengthy review of the development possibilities for engines of this type is then presented and a plea is made that the practical man cast his lot in with those who are trying to make our merchant marine permanent.

The undisputed economy of the Diesel-type engine using heavy fuel oil is recognized, as no other power-generating unit of today shows better thermal efficiency. It is the result of the direct application of fuel in work-

[1]Formerly head of the Diesel engine unit, Emergency Fleet Corporation, Philadelphia.

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ing cylinders, thereby producing heat to do work in the engines in the most direct way. Transmission processes, such as the burning of fuel under a boiler to produce a working agent which must be carried to the prime mover, are less economical. The various factors which enter into a comparison between steam and heavy-oil installations are illustrated in Fig. 1.

Heavy-oil engines have been developed, built and successfully operated in ships, while greater progress is in sight since America has given attention to this means

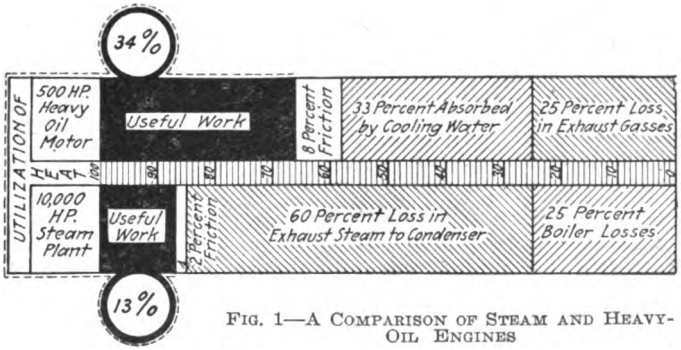

FIG. 1—A COMPARISON OF STEAM AND HEAVY-OIL ENGINES

of propulsion and our manufacturing companies having previous experience with oil engines are now engaged in production of large-size engines for use on board ships. Licensees of European manufacturers located in this country are in possession of leading shipyards, but none of them has been able to produce heavy-oil engines up to this time, owing to the pressure of war work.

To bring as many individuals as possible in contact with the Diesel-engine situation, for the sake of rapid advancement, I have treated the whole subject in a more or less elementary manner. The diagrams and sketches are intended to explain the working principles of such types of two and four-cycle engines as are now in actual operation in cargo ships throughout the world, these engines being of the single-acting type, notwithstanding that double-acting and opposed-piston-type engines have been built and are now being tried out.

WORKING PROCESSES OF DIFFERENT TYPES

Figs. 2 and 3 illustrate the working process of four-cycle engines. Figs. 4, 5 and 6 are working diagrams of two-cycle engines. In each case the various functions

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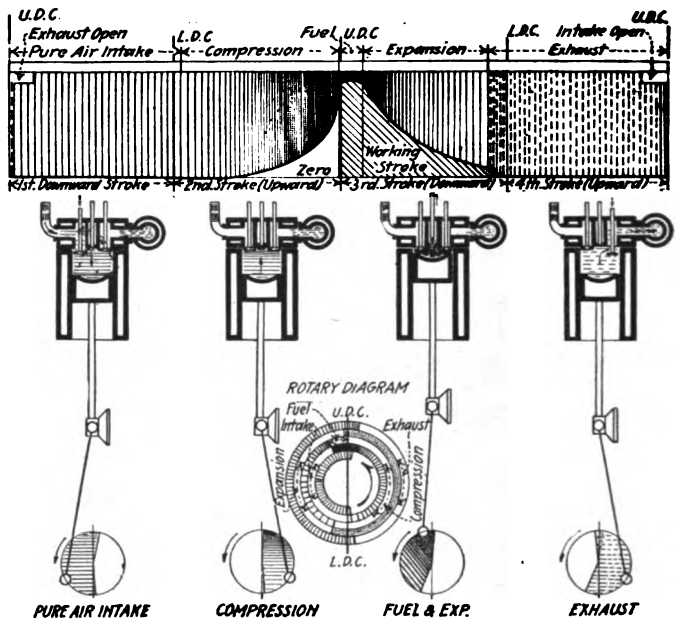

FIG. 2—WORKING PROCESS OF A FOUR-CYCLE ENGINE

during either the upward or downward strokes are plainly described, the dead centers are marked and the free-hand curves shown illustrate the increase or decrease of pressure during the various periods. The valves or ports necessary for any of the systems are seen in the diagrams showing the different crank positions, in addition to the type of piston used. In each case the rotary diagrams illustrate the various functions in succession, in a direction marked by the arrow and in approximate relation to the respective dead-centers.

In the case of four-cycle engines (Figs. 2 and 3) during the first downward stroke, pure atmospheric air drawn into the cylinders passing by the inlet valves, or air taken from the atmosphere and forced into the working cylinder under moderate pressure, either from the top or the bottom in the case of two-cycle engines (Figs. 4, 5 and 6), is compressed during the upward stroke of the piston to a higher degree than is the usual practice in explosion engines. A temperature of approximately 1300 to 1400 deg. fahr. and a corresponding pressure of about 500 lb. per sq.

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in. prevails in the working cylinder when the upper dead-center is reached. At this point the fuel oil is sprayed in, under a pressure higher than the compression pressure, and immediately burns very gradually, without appreciable rise in pressure. This is due to the design of the fuel valves, so that the engine works very smoothly and without shocks, because the sudden rise of pressure, such as occurs in gasoline or other gas engines, is eliminated and the peak load is therefore better distributed. Much depends on the timely injection of the fuel oil which is admitted a trifle before the upper dead-center, and the fuel valve remains open during approximately 12 per cent of the downward or working stroke. During this time expansion can take place at any point while the valve is open, which depends upon the engine load and continues until the exhaust valve in the cylinder-head of four-cycle engines (Fig. 2) opens, or first the auxiliary exhaust valve and then the main exhaust valve opening after that (Fig. 3); and with two-cycle engines until the working piston on its downward stroke uncovers the exhaust ports at

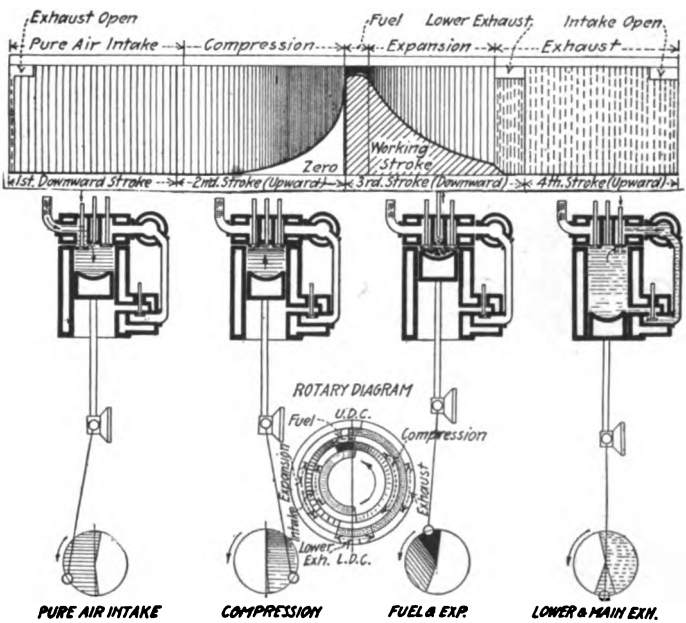

FIG. 3—WORKING PROCESS OF A FOUR-CYCLE ENGINE WITH AUXILIARY EXHAUST VALVE

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the lower end of the cylinder (Figs. 4, 5 and 6). Thereafter, the working process is repeated by the admission of air slightly under atmospheric pressure, which reduction is due to the wire-drawing of the air past the inlet valve in the case of four-cycle engines (Figs. 2 and 3).

With reference to Figs. 2 and 3, the only difference is the application of a so-called auxiliary exhaust valve, arranged for by certain manufacturers to relieve the main exhaust valve from excessive heat. There is no doubt that this arrangement does the work, but the question remains whether additional parts are of sufficient merit to warrant this complication. When the designers take care of the proper velocity of the rushing-by gases, that is to say that when as large a valve as possible is used, trouble can be avoided, although the exhaust valve in any engine is a factor of utmost consideration. Large valves must be water-cooled in addition to their valve cages. The smaller the valve the less troublesome it is, so that two, instead of one exhaust valve, are sometimes

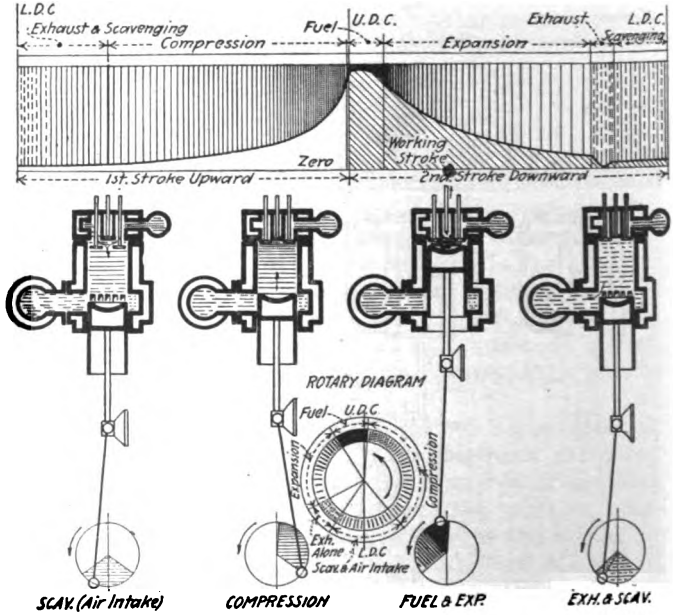

FIG. 4—WORKING PROCESS OF A FOUR-CYCLE ENGINE IN WHICH THE SCAVENGING AIR IS DRAWN IN THROUGH VALVES IN THE CYLINDER-HEAD

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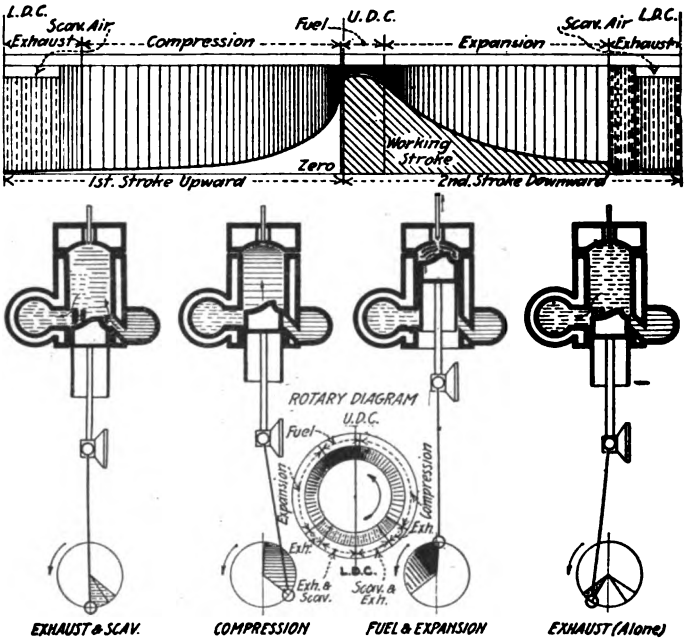

FIG. 5—WORKING PROCESS OF A FOUR-CYCLE ENGINE IN WHICH THE ADMISSION OF THE SCAVENGING AIR IS CONTROLLED BY A ROTARY VALVE

used, which adds considerably to the life of such valves but complicates the valve gear. The use of this auxiliary valve necessitates a row of ports at the lower end of the working cylinders and although of less area than the exhaust ports of two-cycle engines, it is questionable whether such a construction is justified or necessary. When applied to four-cycle engines having a partition between the cylinders and the crankcase, an undesirable feature is dominant. Owing to the height of the working piston, which is of the box type and therefore should preferably be made as short as possible, the communication space between the cylinder wall and the valve detains a certain volume of exhaust gas which is discharged into the engine room every fourth stroke of the engine. This tends to spoil the atmosphere and may prove to have a sickening effect upon the attendants.

In two-cycle engines the scavenging air is admitted under a pressure of 5 to 7 lb. per sq. in., through slots

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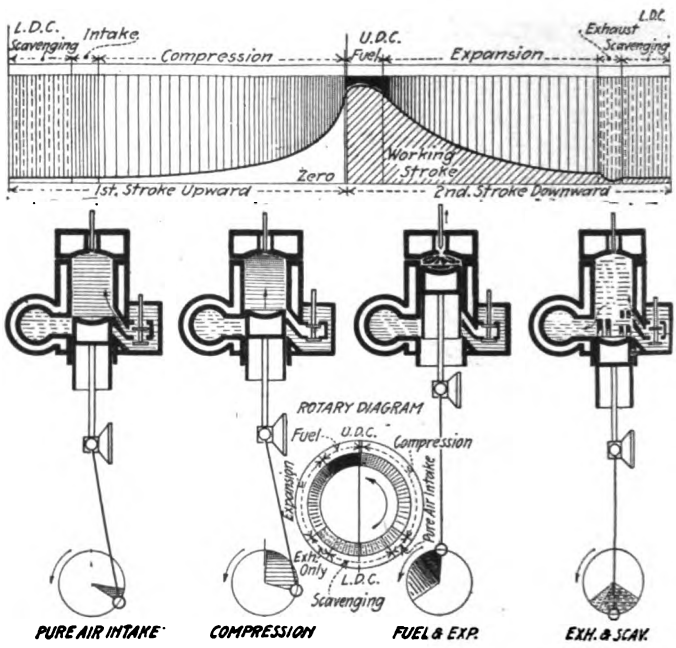

FIG. 6—WORKING PROCESS OF A FOUR-CYCLE ENGINE

(Figs. 5 and 6) located opposite the exhaust slots or through valves in the cylinder-head (Fig. 4).

Fig. 7 shows two types of two-cycle engine; on the left an ordinary piston type, where working cylinders are provided with a common receiver and a direct-driven scavenging pump of either single or double-acting type, sometimes arranged in tandem, which arrangement can be replaced by a rotary blower which is preferably detached, or by a detached reciprocating-pump arrangement. A further possibility is to arrange a so-called annular piston, attached to the main piston as shown at the right in Fig. 7, which eliminates a large receiver but makes the engine that much higher. In practice it has proved to be liable to give trouble in vertical engines owing to the possibility of the blowing of foul gases by the working piston, which in that case invites excessive carbon formation by mixing with the lubricating oil of the annular scavenging piston. An advantage of this type of piston is the possibility of starting the engine by admitting starting air on top of the scavenging piston,

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thus eliminating the extreme cooling down or chill of the walls of the working cylinders, as is the case with the ordinary piston type just discussed, as well as with any other type of engine described in this article. Although there is an apparent advantage in eliminating the starting air from the working cylinders, no trouble has been encountered in well-designed engines, where solutions for the right kind of material to be used are known. Another means of eliminating the starting air from the working cylinders is to arrange the low-pressure stages of the direct-driven air compressor to turn the engine over at sufficient speed to cause combustion of the fuel oil, which is done in certain designs.

Glancing over the constructional features of the two-cycle type as shown, the most efficient scavenging process

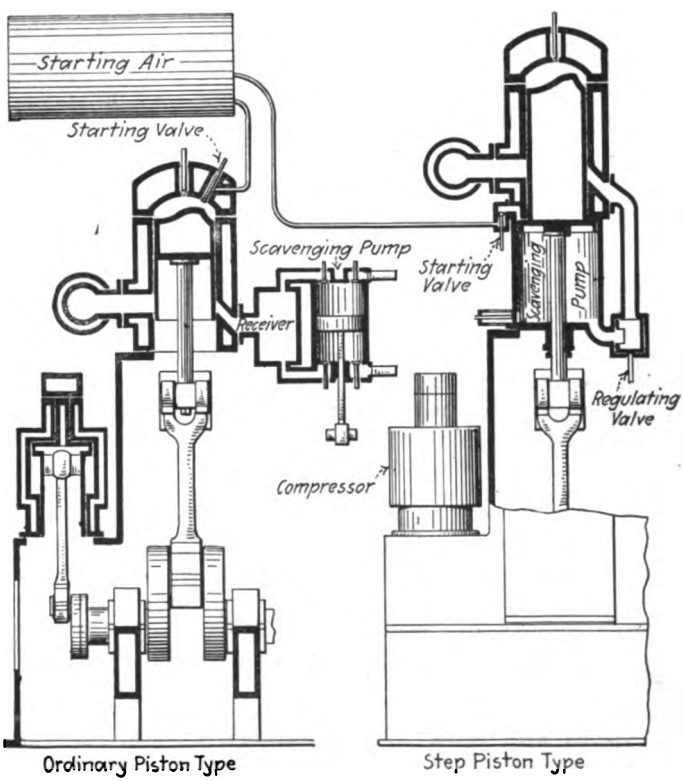

FIG. 7—TWO TYPES OF TWO-CYCLE ENGINE

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can be obtained with the arrangement shown in Fig. 4, where air is admitted from the top by means of four valves and the exhaust gases are expelled from below through a row of ports, equally divided over the whole circumference of the cylinder wall, in which case the expansion during the working stroke can be carried to the limit so that a maximum amount of effective work is maintained. It must be admitted, however, that the cylinder-head is more complicated than with the types shown in Figs. 5 and 6, which is a talking point in favor of engines having port scavenging only. Both types of engine are manufactured with equal success, it being a question of proper design, distribution of the material and the means of cooling.

The simplest design, but also the least economical, is shown in Fig. 5. It is essential that the opening point of the exhaust port be before the point of opening of the scavenging slots. This lead is necessary to reduce the pressure of the exhaust gases at the end of the working stroke, to permit scavenging air to enter, which does not happen until the pressure in the cylinder is practically down to atmospheric, having thus dropped from about 40 to 50 lb. per sq. in. to a pressure prevailing in the exhaust header. In this way the benefit of scavenging air entering at a pressure of from 4 to 7 lb. per sq. in. through the scavenging slots cannot be maintained at the beginning of the compressing stroke, as the air is lost through the exhaust port. In this respect the design shown in Fig. 5 is far better, as an additional row of ports is provided in direct communication with the scavenging receiver; the admission of air being controlled by a double-seated or a rotary valve, thus allowing the compression stroke to start with whatever pressure is available in the scavenging air receiver, which consequently improves the output of the cylinder. The additional gear and valve cages located inside of the receiver, with the necessary doors for access, have not given trouble in practice with well-designed engines, except for the difficulty that the exhaust gases enter this space between the cylinder wall and the valve, causing carbon formation due to the mixing with the lubricating oil carried from the cylinder wall and thus necessitating cleaning at times; but this can do no damage as long as the valves are tight. The advantage of starting the compression period at a pressure above atmospheric and equal to the receiver pressure, is also maintained with

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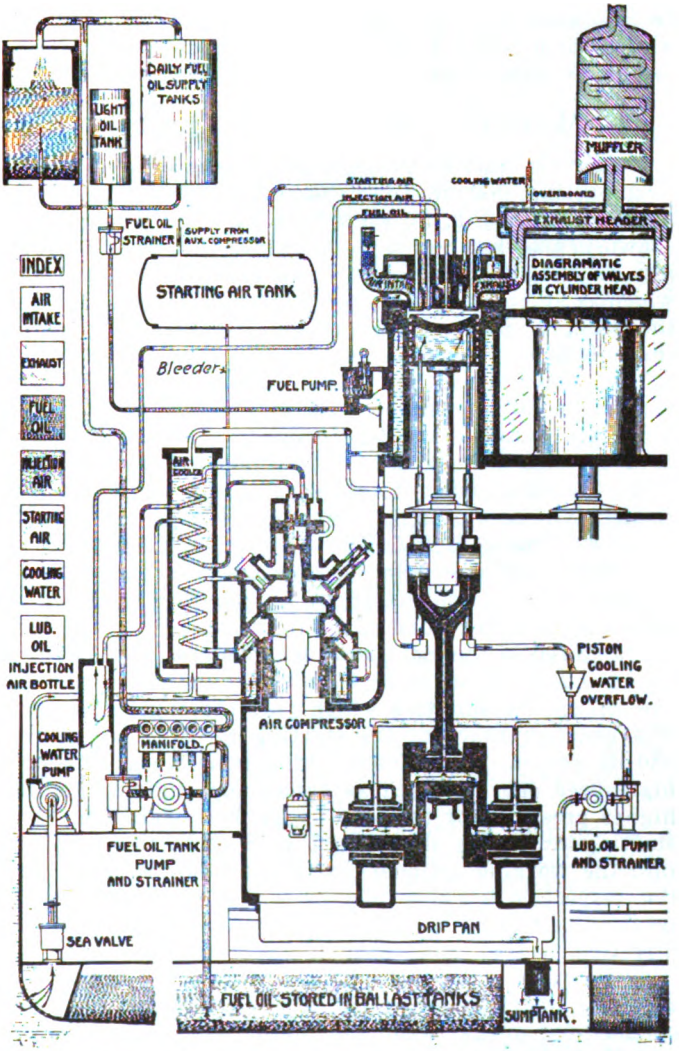

FIG. 8—WORKING SCHEME OF A FOUR-CYCLE SINGLE-ACTING MARINE DIESEL ENGINE

the top-scavenging type shown in Fig. 4. The valves used are not apt to give trouble, as their functions can be compared with the inlet valves of four-cycle engines, which valves do not invite trouble because their seats are not in direct contact with the exhaust gases.

Workings of the Four-Cycle Engine

I will now describe the working scheme of a four-cycle single-acting marine Diesel engine as shown diagrammatically in Fig. 8, in connection with the arrangement shown in the sketch of a motorship in Fig. 9, each drawing practically covering the same subject. Fuel oil, which is stored in the double-bottom or ballast tanks of the ship, is pumped to the daily supply tank, going through a manifold and being filtered before entering; it then flows by gravity to the suction chamber of the fuel pump on the engine. As a rule two daily supply tanks are installed, of 12-hr. capacity each, sufficient for both engines in case of a twin-screw installation; this gives the oil a chance to settle. In addition, there is a smaller tank holding a light oil which is used for starting up in extreme cold weather. The oil is strained on its way down before it enters the engine fuel pump.

Starting air is furnished by an auxiliary compressor shown in the foreground at the right side of Fig. 9. This air is stored in the maneuvering tanks as shown in Figs. 8 and 9 and serves to accelerate the engine before the fuel oil can be admitted which puts the engine on duty. The usual pressure of the starting air does not exceed 350 lb. per sq. in. for merchant marine work, although high-speed engines, such as submarine engines, require higher pressure for the sake of quick acceleration. The starting-air valves shown in Fig. 8 serve to admit air into the working cylinders, at the upper dead-center of the respective working pistons which are in the right position to receive it, and turn the engine over in either direction desired, controlled by the reversing gear.

Compression takes place in the working cylinders not receiving starting air, creating the necessary heat for combustion, so that when the engine is sufficiently accelerated, fuel oil can be admitted to all cylinders at once, or in sets if desired, as a device is provided to cut out the starting air as soon as the fuel is turned on, or vice versa. The handles shown in Fig. 8, in front of the engineer, control this operation and at the same time make it impossible to reverse the mechanism unless the

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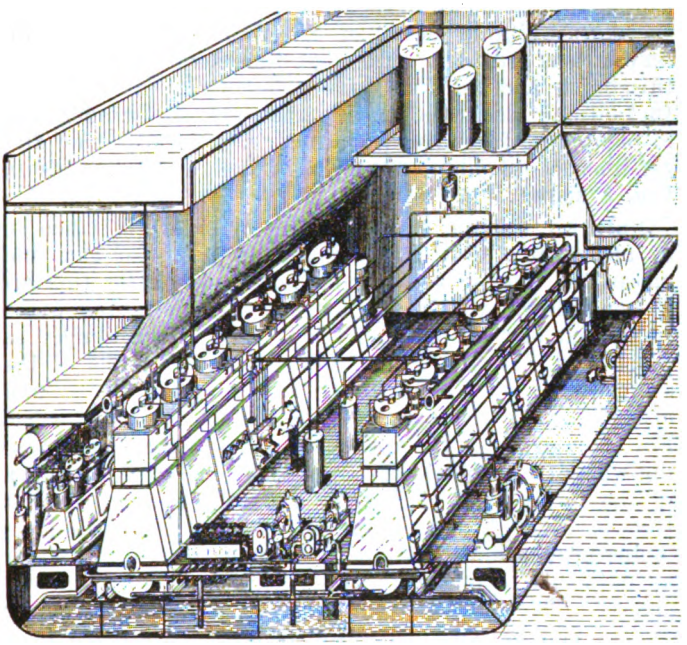

FIG. 9—ARRANGEMENT OF A DIESEL ENGINE AND AUXILIARY APPARATUS IN A MOTORSHIP

fuel is cut off. Air from the maneuvering tanks is carried to the working cylinders by means of a distributer, as shown in front of the operator, at the left in Fig. 9, having a conveniently located hand-wheel.

Fuel oil for the working cylinders is supplied by a high-pressure fuel pump driven from the main engine. It is discharged around the fuel needle and forced into the cylinders by means of high-pressure air, the so-called injection air, which is furnished by an air compressor direct-driven by the main engine or detached therefrom and independently driven. Both figures show this compressor in section and elevation respectively. Fig. 8 illustrates the various features. As a rule, for large engines a three-stage compressor is used. Air is drawn in at the low-pressure stage, discharged through a cooler to the intermediate stage, and thence discharged again through another cooler to the high-pressure stage; from there it is cooled again on its way to the injection air bottle, which is of sufficient volume to give the air an oppor-

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tunity to expand and separate the moisture contained therein. Suitable means of draining this bottle at intervals are provided. The pipe-line connection between this bottle and the fuel valve delivers air on top of the fuel oil and blasts the oil into the working cylinders the moment the fuel needle opens. A study of the diagrammatic assembly of valves in the cylinder-heads in Fig. 8 shows this feature.

Pure air for the main working cylinders is taken in by means of a slotted tube closed at the upper end, and passes the inlet valve. Firing takes place after this air is compressed and the exhaust valve expels the gases to the exhaust header and from there to the muffler as illustrated. It will be understood that the walls of the compressor, working cylinder and cylinder heads, and also the exhaust header and the piston, must be cooled. For this purpose a variable-speed pump is installed, drawing water from the sea through a sea-connection as shown in the left corner of Fig. 8, and at the right side of Fig. 9. The discharge can be regulated according to temperature conditions, and sometimes in tropical water an outboard temperature of 85 deg. fahr. must be considered. The cooling water is discharged around the air coolers and in the compressor jacket; from there it is distributed to the working-cylinder jackets and the piston-cooling arrangement. After the water has passed the cylinders, it flows through the cylinder-head and exhaust-valve cage to the exhaust header and from there overboard. The piston cooling-water overflow usually is discharged into the bilges and from there pumped overboard.

The lubricating oil for the main moving parts is as a rule stored in a sump-tank located in the double bottom, in case a forced-feed system is used. I prefer such a system under all circumstances, as it is superior to and more reliable than a gravity-feed system for this particular purpose on marine installations. The oil in this case is supplied by a variable-speed pump, which can be adjusted to suit prevailing conditions, influenced by the amount of oil required and depending upon the temperature of admission of such oil, which affects its viscosity. Enclosing the crankcase allows the re-collection of the lubricating oil in a drip-pan under the crankshaft; thence it is carried to a sump-tank, located low in the ship. The last-named pump draws the oil from there, passing it through an oil cooler if necessary, and discharges it

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into a main header running all along the engine and having leads to every main bearing. As a rule the oil enters the upper-bearing cap through a suitable groove which has communication with a vertical and horizontal hole in the journal, a vertical or slanted hole in the crank web, and a horizontal and vertical hole in the crankpin. From there it enters a groove in the connecting-rod brasses, a hole in the connecting-rod proper and is thus distributed to the crosshead and guide. Necessary oil for the journal and crankpin is properly distributed from these grooves.

The top of the crankcase is provided with a stuffing box, through which the piston-rod passes. As a rule, with enclosed engines, there is a space between the cylinders and the top of the crankcase, which in some cases serves for the removal of the piston. This space also allows foul gases, passing by the piston, to escape into the atmosphere, thereby preventing them from mixing with the lubricating oil of the moving parts. In engines of the ordinary marine open type, having no partition between the piston and the crankcase, the foul gases come in contact with the lubricating oil and tend to form an undesirable coating on moving parts and surroundings, and also to pollute the lubricating oil. The working cylinders and cylinder-heads are either separate parts or cast integrally. For large engines, loose cylinder liners and separate cylinder-heads are essential, although a combination of the liner and the cylinder-head has been used successfully.

The valve gears of four-cycle engines comprise either one or two air-inlet and exhaust valves, depending upon the size of the bore; one or two fuel valves and a starting valve. All are operated by rocker-arms, rollers and cams. The valve gears for the two-cycle type, arranged for top scavenging, usually show four valves when arranged for port scavenging. A double-seated valve, or a rotary valve, commonly located in the scavenging receiver, is applied. All of these valves also are operated by rocker-arms, levers, rollers and cams.

The reversing of the engine is done in various ways, but as a rule rollers are mechanically removed from one cam to another located on the same camshaft, thus controlling the operation of the engine ahead or astern by a suitable setting of cams.

The designs of fuel valves for the various types of Diesel engine vary in shape and in detail, but their per-

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formance is practically the same, as the difference in actual fuel consumption of well-designed engines is negligible. In most cases a needle-valve or a poppet valve is used, the first being lifted in an upward direction to admit the fuel and the second moved downward to allow the fuel to enter the working cylinder.

Fuel oil is supplied by a high-pressure fuel pump, discharged around the fuel needle and forced into the cylinders by means of high-pressure air. The pressure of this air as a rule varies from 700 to 1200 lb. per sq. in., according to the load of the engine. This air thoroughly mixes with the fuel oil which is thus mechanically broken up into fine particles so that, when oil and air combined are entering the working cylinders, thorough combustion will take place, because the volume of oxygen contained in the working cylinder is more than sufficient to complete the economical burning of the fuel. In some cases the lift of these valves is controlled manually from the engineer's stand. This is of advantage in case the engine runs slow, as at that time a tendency prevails to use more fuel and injection air than under normal conditions at full load, due to the time element. Naturally, additional provision is made to reduce the amount of fuel supplied, as well as a reduction in pressure of the injection air. Most direct or indirect-driven compressors are of such volumetric capacity that they are able to furnish air for two engines at part load, in the case of twin installations, and this is one of Lloyd's underwriting requirements. In other cases an auxiliary compressor of the same capacity as the main compressor is installed; it then becomes possible to reduce the size of the compressor on the engine, which is then designed to take care of one engine only. The auxiliary compressor in such cases is made to serve starting air under normal circumstances. By the so-called solid-injection system, which method tends to cheapen and simplify the engine, it is possible to eliminate an air compressor entirely by injecting the fuel direct into the working cylinder under high pressure, which adds about 10 per cent to the power of the engine. This is therefore a promising factor, although the opinions of engineers differ as to the reliability of such a method, owing to the increased possibility of carbon formation and consequent smoking of the engine in service, although claims are made that mechanical difficulties have been overcome.

Fuel pumps are either of the suction-valve regulation

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or of the variable-stroke type. In the first case regulation is accomplished by by-passing fuel oil from the discharge side of the pump back to the suction chamber, by preventing the suction valve from coming down on its seat until such time as the surplus oil is by-passed; in the second case by changing the stroke of the fuel-pump plunger; in both cases by mechanical devices regulated by hand.

The average design of a marine heavy-oil engine of large size, say from 750 hp. up, is of the crosshead type and resembles ordinary marine steam-engine practice. The advantages of the open-type marine reciprocating engine have been duplicated, and such practice is followed especially where a gravity-feed lubricating-oil system is used for the main moving parts such as the crankshaft, connecting-rods and crosshead. Builders of marine Diesel engines have shown a tendency to abandon the entirely open type of engines, without sacrificing accessibility, enclosing the crankcase totally with portable doors, which allows the application of a forced-feed lubricating system for the moving parts and materially increases the protection against overheating. In fact, it is my candid opinion that this is the only safe way to proceed.

Modern motorships are equipped with electrically-driven auxiliaries, which include all pumps and the ice machine. Direct current for these motors is furnished by a suitable Diesel-engine-driven generator set as shown at the extreme left of Fig. 8, which as a rule supplies current for the ship's lighting system, a motor-generator being used to reduce the voltage from 220 to 110 volts. Modern motor vessels also have electrically-driven deck machinery such as winches, windlass and steering-gear. The current for this machinery is furnished by additional Diesel-engine-driven generators, of suitable capacity to handle cargo. The use of electric hoisting machinery is not new in our Navy practice, but has been used only to a minor extent on merchant vessels in America. Some European vessels have a complete electric deck-machinery outfit, able to handle cargo at speeds considered sufficient for their requirements, but American practice requires speedier cargo handling, so that the desired horsepower increases, and more space is needed in the engine room for suitable equipment.

The heating system throughout the vessel is in some cases operated from a special donkey boiler; in other

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cases by means of electric heaters receiving current from available Diesel-engine-driven generator sets in the engine room. The latter practice seems the most desirable.

Development Possibilities

Regarding development possibilities, it can be frankly stated that United States manufacturers are in as good a position to develop and manufacture heavy-oil engines as European companies that have done the major share in developments as they stand today. From my personal experience, I can say that the duplications of European design manufactured in this country have not suffered the drawbacks of manufacture, such as have been experienced in Europe. This is due in part to the fortunate fact that we have practically started production at a point where the foreigners left off. Moreover, basic materials of high quality, suitable for substitutes for European materials, have been available and applied with great success in many cases. There is no reason to believe that we need much longer depend upon the help of engineers from abroad, as there is talent in office and shop, even though limited, which can be utilized for the education of others, including operating engineers. If possible, steps should be taken by our Government, or by individuals, to prepare to meet future requirements.

Other nations have a sufficient number of men to operate their present motorships because they were the first to adopt this highly economic propulsive power, but they have no surplus. The United States is therefore no worse off in the competitive field than its rivals on the sea. It is for this reason that I make an appeal to the spirit of all engineers, ship owners, operators and legislators to help to promote heavy-oil-engine development thoroughly without delay.

The field for the use of Diesel-type engines on board ship is limited at present, but for the propulsion of vessels at speeds of 10 to 12 knots per hr., with capacities of 5000 to 13,000 tons, the heavy-oil-engine installation will be able to hold its own under all circumstances, it being taken for granted that the bulk of the world's trade is carried in vessels of that size; while the cruising radius of oil-engine vessels is unsurpassed. For instance, a vessel equipped with about 1500 b. hp., carrying 625 tons of fuel oil, can attain a cruising radius of about 20,000 miles with oil engines as compared with 8400 miles with a steam-

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turbine installation, or 7500 miles with a reciprocating steam installation. On long voyages, at moderate speeds, there are no other installations that can compete, even at the present high prices and the comparatively heavy over-all weight. When eventually motorships compete with each other, the methods prevailing to add superfluous material for safety's sake will be abandoned. This will not only bring down the over-all weight, but also the price of installation. There has been no need during prewar conditions to pay close attention to all this, as the earning capacity of motor vessels was so far superior to that of steam vessels that the present changes were overlooked. Increased use of heavy-oil engines on board ship will naturally improve these drawbacks and the final result will be good if confidence reigns with sincere effort.

The limited field mentioned for the use of Diesel-type engines refers to the average cargo carrier, but when passenger ships of greater tonnage and speedier travel are considered the geared-turbine installation may dominate the field for the time being, even if fuel-consumption figures are higher. Advocates of electric drive for vessels with high-speed turbines do not need to fear real competition from heavy-oil-engine installations as it appears to me at present. A greater number of engine units would be needed to drive generators supplying current to motors attached to the propeller-shaft, as Diesel engines have to be made up in smaller units, in addition to the fact that such units can never be run at speeds allowable for turbines, so that the comparative size of electric generators will not be in favor of oil-engine units. Although it is possible to design high-speed heavy-oil engines running at approximately two to three times more revolutions per minute than is customary when applied to motors driving the propeller-shafts direct, the greater number of engine units and consequent increased number of working cylinders may prove to be a detriment, not only from a standpoint of upkeep, but also on account of the factor of first cost. In addition, a larger crew would be required in the engine room to keep the greater number of parts in workable shape. However, attempts now made by leading American firms to introduce Diesel electric drives should be encouraged and investigated by all means, so that we may know at the earliest possible moment what the best possibilities are. Heavy-oil engines of 4000 and 5000 b. hp. each can be built. They are preferably operated at moderate speed for the sake

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of propelling efficiency and applied to twin-screw installations. I see no reason for sacrificing efficiency by introducing a transformation process such as an electric drive, for vessels requiring from 8000 to 10,000 b. hp., although there is no doubt about the high efficiency of the electrical apparatus proper. The flexibility in operation of heavy-oil engines has proved reliable in well-designed ships. Attention is called to the fact that not all designs have been successful and that pioneer installations suffered from the lack of knowledge that has been acquired from experience with them. Heavy-oil engines in general should therefore be judged in that light. There was a time when it was not known how to properly distribute the material while designing, when the foundry was not able to produce satisfactory castings, such as are turned out today, when workmanship of the class required for heavy-oil engines was not applied to this prime mover, which created a sensation in the early days due to its high thermal efficiency. That experience is not lost and will prove to be beneficial to the further development and use of direct heavy-oil-burning engines. A combined effort to produce the goods for the sake of the existence of our merchant marine should be made and given first consideration.

Diesel-type engines will hold their own as reciprocating engines until the time arrives when gas turbines can be built to stand the prevailing heat conditions and show equal economy. Meanwhile we should cooperate and endeavor to at least equal and possibly better the efforts of rivals on the seas, for which we have adequate facilities. Referring to the days of Diesel-engine development when mechanical solutions had been found which embodied the inventor's ideas as nearly as possible, the fuel economy was so far superior to that of the existing steam installations and gas engines of that time that a wide area was opened for the use of Diesel engines in the stationary field. The low price of heavy fuel-oil was at that time an additional factor in its favor. This condition, however, does not prevail to such an extent today. Oil producers have kept an open eye on the market and raised prices in accordance with the demand, which is quite justified from a business standpoint; but even under these circumstances the low consumption of fuel oil in Diesel-type installations will put the engines in demand and prove their merit.

Opponents of heavy-oil-engine installations claim that

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we are not prepared to meet the demand for large engines and are always pointing to what other countries have done or are doing. This is quite right, but at the same time it carries the germ of a lack of confidence in our own production abilities. A visit to shops where successful engines have been produced in smaller sizes than are now sought, and where suitable sizes are now under construction, would clearly show that our products are of sufficient quality to warrant confidence for the future. Another important factor, which is overlooked in most cases and particularly where the price and weight of Diesel engines are commented upon, is that two-cycle engines have not been able to make as much of a showing as have four-cycle engines, owing to the fact that greater difficulties have been encountered in their production. Today, however, we know of two-cycle engines which are reliable and make good records.

It should be remembered that by using two-cycle engines we are able to put 75 per cent more power within the same space, at the same number of revolutions per minute and using the same size of crankshaft, with a corresponding reduction of weight per horsepower; also, when two-cycle engines are substituted for four-cycle of the same power, that the length of the engines is decreased an average of 12 per cent, which also results in weight reduction. In some cases where six-cylinder engines are used, it would be perfectly practicable to use a four-cylinder engine, which would result in a saving of length of approximately 25 per cent.

In an attempt to introduce the Diesel engine electric drive, it should be borne in mind that we are increasing the most difficult factor in oil-engine design; that is, high-speed engines necessary for this work never show the permanent reliability that can be obtained with moderate-speed engines. Although it must be admitted that the weights of high-speed engines compare very favorably with those of moderate-speed engines and therefore make the proposition tempting, we are thus entering a new development which may delay the use of economical power for our fleet at present. The tendency to refer to work performed by Diesel engines in submarines, for instance, does not warrant an attempt in that direction, as it should be realized that increased speed affects the over-all efficiency materially, in addition to the greater problem in overcoming the action of the heat conditions in high-speed engines, which factor does not need much

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explanation to those who have experience with such design. The most visible solution for power, for cargo carriers at least, seems to be to encourage builders of moderate-speed engines for direct-drive engines of the kind that are now being built in the United States. After we have given the manufacturers a chance to perfect their product and gain additional experience, we could look forward to further advancement in the art. To attempt the most difficult problem at present seems to invite delay; furthermore, we may rest assured that manufacturers abroad are no better prepared than we are for such attempts, so that we would not lose by following this conservative course, as they are mainly trying to bring down the speed of direct-driven engines and place as many working cylinders in a given space as possible. The electric drive, however, has advantages for smaller installations such as yachts, etc., so that the benefit of attempts to develop this kind of drive can be seen from the start.

Cylinder bores as applied to small power units do away with the greater part of trouble in high-speed engines, but for units where thousands of horsepower are required to drive electric motors direct on the propeller-shaft, we are not prepared to meet all conditions, as such high-speed units have not been built for commercial vessels of large size and a great number of small units seem to have questionable value. But let us prepare, cooperate and finally succeed in bringing about a satisfactory solution of this important problem, which is closely connected with the subject of the world's fuel supply.

Considerable reduction of engine-room space will follow the efforts of engineers to design the highest possible power within the least space. It can therefore be expected that rules governing the capacity of the engine-room space may need revision in the future. At present such attempts would be handicapped by prevailing port rules, as a ship with an engine-room space above 13 per cent of the gross tonnage has the advantage over a vessel with an engine-room space of 30 per cent or below, in tonnage allowance for engine room, to such an extent that the extra port charges for a vessel with a small engine room may more than offset the gain due to the extra earning capacity.

Finally, I have a word for the practical man, the operating engineer. In the early days of marine oil-engine

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construction, the prejudice of steam engineers had to be met. They were particularly opposed to the efforts made by engine builders to enclose crankcases, which eliminated the possibility of touching bearings and crankpin boxes with their hands, because they considered this absolutely essential. Provisions that were made on reciprocating steam engines to sprinkle water on the main bearings and crankpin boxes were necessitated by the gravity-feed lubricating-oil system, but by admitting an abundance of oil under pressure, reliable results are obtained. However, to become accustomed to this different practice seems to create a hardship for the older operating engineers. The younger element will naturally be found to be without prejudice. The idea prevailing from the beginning that marine oil engine manufacturers had solved all problems, and the attempt to adhere to reciprocating steam-engine practice as far as possible, have shown their effects, and all parties have had ample opportunity to familiarize themselves with actual necessities and requirements. The dangerous art of copying without thorough knowledge of all conditions has done its share toward giving a bad reputation to some makes of engines.

A handicap for the United States, in attempting to hold her own on the seas as a maritime nation, is the specifying of the amount of labor to operate the ships. In one instance it was said that American ships could not sail unless practically twice the number of oilers were put on, such decision apparently being based on steam-engine practice. Such rules do not seem to be justified, as modern Diesel installations are as a rule provided with mechanical lubricating systems and therefore require less human attendance.

From experience, I can state that while en route, with things in working order, no hard or strenuous work is thrown upon the operating engineer or his assistants. The general conditions for the engine-room crew are very favorable, particularly when we consider the comfort in warm weather when the engine-room temperatures are very moderate. In port, while inspecting or overhauling, skill is required; for that reason I appeal to the practical man to cast his lot in with those who are trying to make our merchant marine permanent, for the benefit of all Americans, as it can be expected that the training of men to operate such ships as have been described cannot fail eventually to be taken up by the Government or by

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firms interested in the manufacture and operation of motor vessels.

The Discussion

W. N. Howell:—Concerning double-acting engines with piston-rods, I had about two years' experience with an experimental engine having 8-in. bore and 12-in. stroke; we had no trouble with the piston-rod. We cooled the rod and the piston by circulating oil in them. We used a long packing of white metal around the rod, in strips or threads which were packed into the stuffing-box, mixed with graphite and set up by a gland until we could get nothing more, then the gland was slacked back a little and it formed a perfect packing. It was a two-cycle double-acting engine with crosshead. We finally obtained about 65 hp. from it. No examples of piston-rod engines have been mentioned. What has been the experience with them?

H. C. Verhey:—If the gland can be kept from contact with the solid matter in the gases, they will not corrode it. With an arrangement whereby the solid matter is carried out through the ports, this might be accomplished. I know of several materials that will stand up and make good packing for a rod.

Mr. Howell:—The exhaust was through a triple row of ports in the middle of the cylinder. The piston uncovered them at the top and bottom of its stroke. The scavenging was done by a cone on the top and bottom of the piston. The center row of ports was for the air; above and below it were the exhaust ports. The ports were at the middle of the stroke. There was still a chance left for solid matter to collect around the rod.

Mr. Verhey:—In the long run carbon enough would deposit to give trouble. I believe we ought to stay away from anything like a gland in such a temperature, if we can, even if it is cooled. If the demand for double-acting engines arises, there are possibilities of obtaining increased power within a certain space without the use of a design having a piston-rod of the type mentioned; for instance, the opposed-piston type like the Junkers engine, having one long cylinder and exhaust ports at the ends, the upper piston being operated by very long connecting-rods. It is one way of getting rid of stuffing-boxes. Some of these schemes appear all right theoretically, although they have not been extensively tried out in marine

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service. The Fullagar type, partly on the order of the Junkers engine, has two cylinders side-by-side; these are long cylinders with two pistons working in opposite directions, and having the lower and the upper pistons of each of the working cylinders, which are located side-by-side, connected by means of angular tie-rods. So, there are two pistons working side by side and moving in the same direction. They obtain fairly good efficiency on the crankshaft, in this way. In an engine of this kind we are obliged to build four cylinders per unit. If it is desirable to use a design of this kind as a marine engine, eight cylinders are required because the cranks of the single unit stand at 180 deg., thus having an objectionable dead-center for starting unless an attempt should be made to start on the compressor. I understand that Mr. Setz is now building an engine with an arrangement to start on the compressor.

H. R. SETZ:—Yes; not in the one now building here, but in some of the eighteen that were built in Italy. They start on the two double-acting cylinders of the low-pressure stage; that is to say, with one down and one up.

MR. VERHEY:—I think that is a good scheme for starting, carrying a moderate pressure of 200 to 400 lb.; some carry it higher. In the early stages we thought it necessary to have 60 atmospheres for starting. This air, rushing through a comparatively small orifice, cools the cylinders down to a great extent. This is probably one of the reasons cylinder-heads and pistons do not last long in some cases. We should maintain uniform working temperature.

W. C. DAVIDS:—Should not each power cylinder have its own fuel pump?

MR. VERHEY:—I can say from experience that this is the best way. For example, in a six-cylinder engine having one plunger for each three cylinders, a distributor box was used and leads carried to each cylinder. We found that the length, friction and bends in the pipes are factors which absolutely affect the delivery. This would vary in each case, so that there remains only one satisfactory way and that is a fuel-pump plunger for each cylinder; that is what is adopted by most builders. They are generally integral, but perform independently. The older types are very interesting. The motorship Selandia has the real history of development. She started with an air compressor driven from the main engine; but only the high-pressure stage, an auxiliary compres-

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sor having three stages, delivered air into the starting-air tanks at about 350 lb. per sq. in., which is the approximate pressure that occurs in the second stage of a three-stage compressor. That air was carried to a separate high-pressure compressor, driven by the engine. This system has since been discarded. There has also been a change in the fuel pumps. In the early days distributing boxes were used, but they have since been done away with. The friction in the lines is such that it must be taken care of in a positive way. This is the reason not all engineers approve the scheme that the Dutch are using in order to eliminate a fuel pump. They use a floating vessel filled with fuel oil, with injection air pressure on top of this oil, and with an arrangement which supplies just so much oil, which is carried to the engine through leads from the floating vessel and goes to every working cylinder. The length and shape of these lead lines differ according to the location of that apparatus; also the viscosity of the oil differs at different times, so that the actual discharge is affected and does not remain constant. Adjustments must be made at times, so that the human element is introduced again. The same thing holds true of a gravity-feed lubrication system. It becomes necessary to regulate the feeds at different times of the day. We should get rid of that. We want to have something more positive.

Solid Injection

E. A. Sperry:—What knowledge is there of solid injection systems and the results of engines equipped with them? We have seen on the screen many details of the super-air-compressor, which is really the curse of the Diesel engine. We have heard much about the Germans' contributions in this line, but nothing about any contributions by Anglo-Saxons. The most crying need is the elimination of the super-compressor. This has been accomplished in a practical way. Hundreds of engines are operating in this manner, touching the highest economy in both consumption of air, 2.7 cu. ft. per hp. per min., and fuel consumption. Yet we have heard nothing about this in this otherwise exhaustive review of the subject. I refer to the English contribution by the Vickers company, and I firmly believe we are to hear of still greater practical improvements when the Anglo-Saxon finally gets under way on this problem.

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MR. VERHEY:—It is a very good scheme by itself, a scheme which eventually will affect and interest all manufacturers, because with the solid injection system 10 per cent of work in the engine can be saved. A good fuel consumption seems to be obtainable. Engines appear to perform well and reach good economy, but it seems that the combustion is not perfect at all times. I have heard statements to the effect that you could tell a Vickers company Diesel ship by its smoke, from a distance. It is said that with everything adjusted for fixed conditions, at full load and with a certain kind of fuel oil, preferably a light oil, no such trouble is encountered; but when a different load is carried the working principles seem to be affected. This is also one of the reasons other makes of Diesel engine are not as economical during changes of load, because there is no proper means of regulating the amount of air and fuel at different loads under all circumstances. Take semi-Diesel engines or engines of the Hvid type, the latter gasifying the fuel in a little cup before it enters the cylinders. It is perfectly satisfactory as long as the load is constant and the same kind of fuel is used; in general, when all conditions are just so. With a continuous variation of the load, combustion may not be clean at all times; the little holes are carbonized and clog up; then the over-all efficiency is gone. In general, injection air seems to have some effect on the proper combustion and surely has a cleaning effect on all passages where fuel oil and air go together; that is, around the fuel needle. This leads to prolonged economy. There is no question in my mind, however, that we should all look forward to doing away with the air compressor if possible. There is no reason why we should waste a good 10 per cent of work; in addition we would simplify the engine considerably and thus reduce the cost of it.

L. C. MARBURG:—In tests of a two-cycle engine equipped with a Leissner gasifier, we have successfully used Calol oil having about 52 per cent asphalt. The engine was of 20-hp. capacity and operated at 500 r.p.m.

MR. VERHEY:—I have never seen any detail. It seems that there would be no reason for trouble if we could arrange the system so that fuel would be admitted at the very lowest point of the cylinder-head disk, making the arrangement such that no internal firing could take place inside of the fuel-valve cage. If we can put that into practice, it would undoubtedly be an excellent thing.

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MR. SPERRY:—We find that there are about eighty engines which run that way. I have some of those nozzles on my desk and they make an extremely favorable impression. As you say, the oil efficiency is high.

ARTHUR WEST:—We want to use oils in this country of perhaps 15 Baumé gravity, which have an excess of 50 per cent asphalt. Is it the opinion that the chances are good for solid injection using that kind of fuel oil?

MR. SPERRY:—Our information is that they can use any kind of oil that will flow. I know positively that they have used Texas oil and California oil. They rate oils in England on a slightly different basis than we do here and talk a great deal about the paraffines. There is no stoppage of the nozzles due to the fuel unless it is dirty.

A MEMBER:—How about the carbon formation?

MR. VERHEY:—Clean burning is the dominating factor throughout. If we could find the means of doing away with troubles of that kind we would be on the right track. Furthermore, I do not know much about the details of the Vickers engine. I know naturally that fuel oil must be broken up before it enters the cylinder. With the needle-valve used, there is a certain distance left between the lower face of the cylinder and the point where the oil is released as a broken-up unit. Traveling that distance, oil may collect again, and it may come out in a body. If we can get a solid-injection system where oil is injected absolutely at the lowest point of a cylinder, no carbonization could take place; and I cannot see why we could not burn clean at all loads, because there is plenty of oxygen waiting. I would say that it might be a matter of design.

MR. SPERRY:—The matter of doing away with the super-compressor is so very important that I am glad to hear you say that it is a desirable thing to avoid. We have evidence, which we believe is thoroughly credible, that a complete set of nozzles in a large pair of engines have run 27,000 miles without being changed. That does not seem to indicate that they are easily stopped up, or that there is a tendency to stop-up from causes internal to the cylinder itself. There is no carbonization that reaches back. It is true that there is a little cavity between the points of the valve.

A MEMBER:—I wish to ask Mr. Sperry regarding the engine with the solid injection whether they finally got good regulation? That is, do they get variable speed,

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with control from full down to low speed, without trouble, running long periods at low speed? In a single pump in a certain kind of engine, we have tried a certain oil pumped by the one pump and handled through distributors to the different cylinders. We were unable to use that and so added 15 per cent kerosene. In another make of engine of practically the same dimensions, in which there was an individual pump for each cylinder, we secured better results with that oil than we did with the lighter oil.

MR. SPERRY:—They operate about as all Diesel engines do; down to about one-third of the speed, perfectly, as far as I can say. The secret of the success of those engines seems to be that there is a flattened tube close up to each one of the injection valves, and then an air-chamber effect at the pump. That combination seems to be the one that is doing the work that I describe.

MR. VERHEY:—I would like to know what happens when the engineer cuts down the fuel to bring the speed of the engine down. Is he regulating the pressure on the system? Does that follow at all times? For instance, without air injection, is any means provided to take care of that regulation? Is a relief valve of some kind used?

MR. SPERRY:—Just a small eccentric on the air-injection-lever fulcrum which makes the cam roller dip down on the cam more or less. Regarding the oil injection, the oil-injection valve at the nozzle is governed entirely as to the duration of its opening by rotating this eccentric. As to the lift of the fuel needle, that system is never governed through the pump at all; it is governed by the above mentioned method, and the lift of the needle is simultaneously varied.

MR. VERHEY:—The same as on the German engine, where much is done by hand. There is a change for the lead with a consequent change for the needle lift. Most four-cycle engines have not such provisions. I have seen it work all right on two-cycle engines and I think it is an ideal solution. It is the coming way, and beneficial when running slow.

LUBRICATION

H. COOKE:—It has been said that some prefer gravity to forced lubrication. I think there is a place for both. In regard to the gravity lubrication, one important thing in the Diesel engine is to lubricate the cylinders without

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any excess of lubricating oil. In the trunk-piston type of engine, if we use forced lubrication we are apt to get more lubricating oil in the crankcase than is desirable. Moreover, it is better to use gravity lubrication to avoid excessive cylinder lubrication. In the larger sizes, in which the pistons are cooled, I think when the cooling system is entirely separated from the lubricating oil by a diaphragm, with the piston-rod running through a stuffing-box in this diaphragm so that the lubricating oil has no chance whatever to lodge on the cylinder walls, there is no objection to forced lubrication. We supply the oil through the bearings, crankshaft and connecting-rods in a way very similar to that shown on Mr. Verhey's diagrams. In that case, the diaphragm also prevents any chance of the salt water from the piston-cooling system getting down into the lubricating oil and causing trouble. If the salt water gets into the lubricating oil it will give trouble all through the oil system.

MR. VERHEY:—I believe that forced feed is superior to gravity feed, at least for marine Diesel engines, and shows its particular advantages with the partition between the working cylinder and the crankcase. In engines of the trunk-piston type we have to make special preparations, such as splash guards over the cranks, in order to keep the flying oil from reaching the lower parts of the trunk and the cylinder wall so that, in the case of your 750 b. hp. engine, the forced-feed system would bring you more complication than the gravity system now adopted. The earlier Diesel engines were all equipped with gravity-feed systems, following marine steam-engine practice, but the tendency is clearly shown to abandon it. I had occasion lately to see a 1200 b. hp. Carels engine on the test stand in Milwaukee. It is equipped with gravity feed, is of the cross-head type and clearly demonstrated that the moving parts are throwing lubricating oil in all directions. This is shown at one side of the engine, which is not entirely enclosed, and appears in the form of a vapor. Such vapors naturally spoil the atmosphere in the engine-room, creating a more or less undesirable odor. All this can be done away with in case we adopt an entirely enclosed crankcase, which goes hand-in-hand with the forced-feed lubricating system.

MR. COOKE:—In regard to that odor, I came across a Norwegian engineer and the first thing he did was to smell the openings in the crankcase. He said that is the way to tell whether the engine is operating well.

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MR. VERHEY:—When foul gases pass by the pistons and mix with the lubricating oil, carbon is formed which settles on moving parts, particularly on the walls of the crankcase, forming a nasty coating. What vapors mean in a crankcase is clearly shown in engines that have oil-cooled pistons, where the return oil is discharged into the crankcase. This forms a coating of small ripples, which apparently build up in course of time, as observed on Danish engines with oil-cooled pistons. It is far better to carry the return piston-cooling oil outside of the crankcase and thence to the sump-tank independently of the lubricating oil, although they may come together in the same sump-tank; but the piston cooling oil is preferably returned through a strainer, which holds carbon back. Excessive lubricating oil may make piston rings stick, in which case the gases will flow by, so that I really believe that the enclosed crankcase is the best solution of the problem.

MR. COOKE:—There is one thing that brings gases down into the crankcase; it is an excess of the lubricating oil sticking-up the rings. When the rings are stuck, the gases pass by. It is really the effect of excessive lubricating oil. Another interesting thing is that in the case of our four-cycle submarine engines which have forced lubrication, we take a great deal of pains to keep lubricating oil off of the cylinder walls. As showing the effect of excessive lubrication of cylinder walls the starboard engine of a submarine went fine. The port engine went fine for about five hours and then a fuel-valve needle stuck. We thought that the needle was bent, changed it and ran five hours longer. It stuck again, and they changed the needle in the valve again. Then they pulled the piston up and found it was all gummed-up with oil. The whole trouble was that the lubricating-oil outlet in the base was so located that it did not clear itself properly. We found that by freeing the lubricating-oil pipe the trouble with the fuel valve was eliminated. That gives some idea of the extent to which lubricating oil will go; it went up into the fuel-oil valve.

MR. VERHEY:—On the first engine for submarines that we designed, considerable trouble was encountered in keeping the lubricating-oil consumption down. It was extremely in excess of what we expected, and we had to experiment in building proper splash guards. The exhaust showed a white smoke and to determine whether

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this was lubricating oil, to satisfy ourselves thoroughly I heated a piece of iron, dropped fuel oil on it and noted that the smoke coming off was black; whereas, that of the lubricating oil showed a blueish white. A man asked me a question about the little pump located near every cylinder and we learned that oil was supplied by a rotary pump and discharged in a header running along the engine, small leads therefrom going to each working cylinder. The engineers must have been under instruction to work these little pumps by hand at certain intervals as determined by practice, as there is no question whatever that lubricating oil must be discharged against the working piston at a height approximately between the second and fourth ring. The working pistons had a wiper ring, but I did not see splash guards. How this is worked out I do not know.

MR. COOKE:—I noticed on the submarine engine we visited that it seemed they were lubricating the cylinders right off of the main forced-feed system. They may have something in the cylinder walls that regulates that oil to the cylinders.

MR. VERHEY:—Mr. West, have you noted the fact that oil can be splashed against the wall and not creep up and gum the ring?

MR. WEST:—Not on that particular engine, but before the war, in one of the German yards, I saw an arrangement in which the connecting-rod went up into the piston, there being a shield over the bottom of the piston. But they made the sheet on a radius concentric with the crosshead pin, and then formed on the connecting-rod a shield which covered it nearly all the time. This very nearly covered the slot. During the war the Germans were very short of lubricating oil, and it not only would have been very disastrous to them to waste oil to such an extent as to get on the rings, but they also would have lost the oil. One of the things which was putting them out at the end of the war was lubricating oil. I think we can be quite sure that in some way they did surmount the difficulty on this German submarine-type engine.

MR. COOKE:—On the smaller engines, they have done away entirely with direct cylinder lubrication in the Swedish factory. They get enough lubrication from the splash, the oil getting up to the cylinder walls from the moving parts.

A MEMBER:—Mr. Cooke made a remark about lubri-

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cating oil getting up in the fuel valve. How is it possible for it to get in there through the cylinder?

MR. COOKE:—I cannot account for it.

MR. VERHEY:—Through the spray?

MR. COOKE:—Just through the nozzle. We cannot tell just why it did that, except that we did know that while the excess lubricating oil was there the fuel-valve needle kept sticking. We then took it out and found that it was all gummed up, and after the lubricating-oil overflow pipe was freed, so that there was no excess lubricating oil, there was no more trouble with the fuel-valve needle.

A MEMBER:—Could it not get through the nozzle?

MR. COOKE:—I do not see how it could, but the actual fact is that the needle kept sticking. I think it stuck a dozen times.

A MEMBER:—I was there and studied the question. They took their oil from the small branches that led to the cylinder. They have a valve there which is shut off when the engineer opens the valve and admits oil.

MR. VERHEY:—It is simply a question whether or not it splashes. Mr. Jackson can tell whether an engine can run on lubricating oil. Did you not have trouble with the drain in one of your Diesel engines?

L. B. JACKSON:—We had a 75-hp. unit and when the drain in the base plugged and the engine throttle was shut off, it would run on the lubricating oil for a considerable length of time; but that happened only when the engine was overheated. It would run on the lubricating oil until the temperature dropped considerably. It must be a typical experience.

HERMAN LEMP:—In our Erie yards we have been operating for some time a 200-hp. two-cycle oil engine, used in connection with electric drive, for switching cars. This oil engine has an enclosed crankcase and the lower portion of the pistons are provided with scraper rings to scrape off any excess of lubricating oil thrown against them from the crankcase. In spite of all precautions some of this oil will go by the scraper rings and show itself as a blue haze in the exhaust, and some will overlubricate the regular piston rings and cause them to gum up. The lubrication of these rings has been provided for by a positive-feed McCord lubricator and, since it was found that with a closed-crankcase type of engine oil will go past the scraper rings in more or less quantity, it was thought that this amount of oil would perhaps be sufficient for properly lubricating the piston rings, and

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that what was really needed is a means for thinning out the oil in the piston rings to prevent them from gumming. Consequently we started several months ago the practice of replacing the lubricating oil in the McCord lubricator by pure kerosene, and ever since this practice was inaugurated the rings have remained open, were found to be sufficiently lubricated, and the blue haze in the exhaust has completely disappeared.

MR. SETZ:—Concerning over-lubrication, I wish to cite a case from my own early experience where this became a feature of advantage. It was on one of the first high-speed four-cycle engines built in Europe. The fuel consumption guarantees were such that when it came to the final test we could not quite attain them. The engine was lubricated by circulation of oil under pressure at the different bearings and connecting-rod boxes; in our desperation we increased the oil pressure and the fuel consumption at once decreased so that we easily met the guarantees. Today, an account would certainly have to be given for the gray exhaust which was caused by our method of "improving" the fuel consumption.

MR. SPERRY:—This strange effect which occurs in Mr. Cooke's spray valve might be very easily explained. If the lubricating oil gets past the rings up into the combustion space, it is there in the form of fog or vapor. Just at the moment that super-compressed air comes in, there is a refrigerating effect, the fog will tend to condense at that point and the oil will collect at the coolest part, which is, of course, the nozzle. I think possibly that might be just what happens.

MR. VERHEY:—It appears so.

EFFECT OF SULPHUR

MR. MARBURG:—We found in connection with coke-oven gas that the damage done by sulphur was particularly great in the presence of an unusual amount of water. The reason for this is quite evident. Is there any way of keeping the humidity out of the oil, if oil containing a large amount of sulphur is to be used?

MR. VERHEY:—If we heat it, we will do away with some of the water.

A MEMBER:—You have to heat it considerably to boil the water out of it.

MR. VERHEY:—No, we do that this way. We pump the oil from the bottom tanks to an elevated tank be-

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tween the shaft tunnels, where it has a preliminary chance to settle, and by taking the oil off at a high point we have a good opportunity to leave most of the water behind; from there on it goes to the daily supply tank where it stands about 12 hr. and, in case we are using heavy oil which must be heated, we are in a still better position to get rid of water in the oil.

A MEMBER:—The trouble we had was with the exhaust valve, almost entirely; it was not with the pistons or other parts. The two-cycle engine would be free from that objection because it uses port scavenging and there is no exhaust valve as such.

MR. VERHEY:—I think that two-cycle engines are far better off in that respect.

MR. COOKE:—In some investigations made in Germany after the engine ran for some time it began to labor. Upon investigation it was found that it had excessive back-pressure. It was found also that the exhaust pipe was filled with a deposit of sulphate of iron. The reason was that the exhaust pipe was so long that at the end it cooled below the dew point, so that the steam in the exhaust gases, caused by the hydrogen in the fuel burning to H_2O, condensed. That picked up the SO_3 in the exhaust gases, caused by the sulphur in the fuel burning to SO_2, and made sulphurous acid. The SO_3 I believe would be inert if it was anhydrous, but when it was picked up by the water it was very active; it attacked the iron pipe and filled it up with sulphate of iron. I believe that is an unusual case.

A MEMBER:—Is it possible to use 6 per cent sulphur oil in the Diesel engine?

MR. VERHEY:—In two-cycle engines it might not be noticed so much as in four-cycle engines. Whether it is very desirable in the long run is another question, but not many oils contain as much sulphur as that. On a four-cycle engine trouble might be experienced earlier than with a two-cycle. As a matter of fact, most manufacturers specify a limit from 2½ to 3 per cent. In general, any oil can be used that can be burned under a boiler, where excessive sulphur would also give trouble; although a little better condition prevails, as steam may have a cleaning effect on the nozzle. Some manufacturers claim not to be at all worried about the sulphur content in the fuel.

A MEMBER:—Does that trouble appear as a lubricating trouble or in the pitting of the valves?

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MR. VERHEY:—In the pitting of the exhaust valves; it also affects the cylinder walls.

A MEMBER:—In building gas engines to operate on gas from coke ovens and also on gas from oil stills, we built many four-cycle engines for the Standard Oil Company to run on oil-still gas. The sulphur does not as a rule pit the valves, unless the engine runs a considerable portion of the time at rather light loads. At heavy loads it does not cause pitting. At light loads, temperatures get down to a value that will cause pitting. I think it is reasonable to suppose that gas engines using this oil-distilled gas is roughly a parallel case to Diesel engines using sulphur fuels. That is our experience.

NOZZLES AND LOW-GRAVITY OILS

A MEMBER:—Will an open and a closed nozzle each handle low-gravity oils with the same satisfaction? Take, for instance, an oil of 14 deg. Baumé gravity.

MR. VERHEY:—The advantage is at all times with the closed nozzle, where we have control to force the oil through. In addition to that, assuming that you refer to a case where injection air is used, the cleaning effect of injection air puts weight in the scale too, as it forces and takes the last particles of the fuel oil off surfaces where they might otherwise hang, carbonize and give trouble in the end.

A MEMBER:—Just how low in specific gravity can an oil be used in the Diesel engine?

MR. VERHEY:—As low as 12 deg. and we can use any oil which will flow through pipes. If too low a degree Baumé, we must heat it to be able to handle it. Any oil that can be used under a boiler; such oil as we are using in our oil-burning ships can be used in Diesel engines if we choose to use it.

A MEMBER:—Are you putting in heating coils?

MR. VERHEY:—We will have to lower the viscosity of the fuel oil either electrically or by means of steam, so that it will readily flow through the pipes. This is an interesting point, as on several occasions I found that conclusions are drawn based on what practice is followed by European builders of four-cycle engines and in successful ships that visit our harbors regularly. They want to take no chances, absolutely following the way of least resistance. Their engineers are under instructions to buy nothing less than 24 deg. Baumé oil, as this is the kind of oil suitable for their particular design of fuel

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valve and all adjustments have been made accordingly. It has occurred that heavier oil proved to be troublesome for these particular types of installation, whereas other types having a differently designed fuel valve might have been able to use this oil satisfactorily. Mr. Cooke can tell us about that, as several of his four-cycle engines are successfully running on Mexican oil of very low gravity. Two-cycle engines are in a better position to use heavier oil. For that matter, large two-cycle engines of the Nordberg type now running in New Mexico have been successfully using 12 deg. Baumé oil for a long time. Some time ago I found that some of my professional friends in a search for handicaps for Diesel installations were not entirely satisfied with my statement regarding the possible use of oils heavier than those used in the installations mentioned, and were apparently of the opinion that 24 deg. Baumé oil was the best that could be done in Diesel engines. In an effort to go down to rock-bottom facts, I consulted such men as Mr. West, Mr. Cooke, Max Rotter, Mr. Jackson, Mr. Nordberg and Mr. McCarthy, all of whom sent me a résumé of their experience and opinion, really showing that there is no objection whatever to the use of heavy oils in either four or two-cycle Diesel engines. I hope to embody the various remarks of these engineers in a later article. It is not the quality of the fuel oil that should worry our competitors advocating steam-driven power, as the only important questions are the weight and price of Diesel installations, because their economy cannot be questioned, even if we should be compelled to use more expensive oils. European-made installations, now closely watched owing to their success, are using higher-priced oil than American oil-burning ships, for no other reason than that while they were practically holding the field alone the oil they most desired was easily obtainable, and, owing to the great cruising radius of their ships, they could bunker a sufficient quantity so as not to become dependent on the local supply available at different places in the world. I feel sure that eventually all manufacturers will attempt to adjust their designs to meet the change of conditions.

Two and Four-Cycle Engines

A Member:—The two-cycle Diesel engine has some theoretical advantages over the four-cycle, such as the working stroke, smaller bore, etc. We have the experi-

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ence of the Italians, who build two-cycle Diesel engines of the same horsepower as four-cycle. They find that there is absolutely no gain on account of the pumps, scavenging apparatus, etc. What would you advise, to use only the four-cycle engine or not?

MR. VERHEY:—That brings the issue to a focus. There is practically no competition between motorships today because there are not enough of them, but when competition comes the ship owner will look first of all to what the installation will cost and how much cargo he can carry in the ship that he intends to equip with oil engines. We know that the two-cycle engine can be built shorter than the four-cycle, for the same horsepower. Therefore, there is a gain in weight and a gain in cargo space; also, if we should follow a line of development doing away with direct-driven pumps, it is possible to make an engine-room arrangement whereby the space can be utilized far better than before. The general layout of engine rooms being practically identical, no matter what the make of engine, practically the same general arrangement is seen in motorships equipped with four-cycle engines, that have a reputation. All that will change. With a number of American companies interested in the development of motorships, improvements can be expected which will abolish all trouble, and the two-cycle engine will be the coming marine engine. What we want is the lightest engine in the smallest space. The two-cycle engine can be built in simple form, without question. I have designed high-speed two-cycle engines varying from 300 hp. to 900 hp., all sizes, with six cylinders. A 500 b. hp. four-cycle engine having a piston speed as high as 1100 ft. per min. was also successfully built. These two-cycle engines based on the principle of double-port scavenging were placed in some of our submarines and have been a good demonstration that, with proper design and workmanship, it is possible to produce maximum power in a limited space. We had to satisfy the Navy Department and show that two-cycle engines could be made to run and stand up, as there was little confidence prevailing owing to the failure of other types. The future development of larger types of two-cycle engines will see the top scavenging principle come to the front again. In any engine we have to look for a scavenging process whereby the exhaust gases are not penetrated but expelled in such a way that there is a minimum disturbance of the column of exhaust gas to be driven out

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through the ports at the lower end of the working cylinders. Difficulties encountered in the early days with cylinder-heads and pistons can be overcome, so that the way of least resistance by eliminating valves in the head need not be followed any more. I predict that the two-cycle engine will be the coming engine, not only on the strength of my last statement, but also owing to the consideration due to builders of opposed-piston-type engines which invariably work on a two-cycle principle. When competition brings us to the point where space requirements on board ship are the main factors, it is evident that the opposed-piston types offer an additional step in that direction, where two-cycle engines have already an advantage over the four-cycle type. However, it should be borne in mind that the opposed-piston-type engine has one distinct disadvantage for marine work, because of its height, which becomes an appreciable factor, and overhead weight in a ship is very undesirable. Such engines may perform well on the test stand, but when placed in a ship conditions differ greatly. I saw a Lloyd's survey of the motorship George Washington showing the wear of cylinder walls at one side of the athwart ship center line of the cylinders. It remains to be seen what the performance will be of these tall engines, of which no data based on extended service are available at present. There is a natural tendency for the pistons and liners to wear toward the inboard side, but the motions of the ship affect the wear also in other directions, as disclosed by the Lloyd's survey mentioned.

A MEMBER:—Do the tips of the screws turn outward on the George Washington?

MR. VERHEY:—Yes, for the sake of propeller efficiency. In addition to what I said about the wear of cylinder liners, this was practically the same for all of them. In connection with this peculiar wear it also occurs to me that the consideration given to introducing opposed-piston-type engines for direct drive, which save space, must go hand in hand with the problem of installation of auxiliary power for cargo handling. The tendency to increase the speed of cargo handling requires higher-powered engines which for existing installation practically determine the length of the engine-room and, when we consider that it is desirable to refrain from making recesses in bulkheads for the sake of a clean hull construction, it can be seen that much study becomes necessary. I am convinced that problems of that kind will

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occupy the minds of many engineers interested in the production of motorships.

MR. LEMP:—I am in favor of the two-cycle engine. In 1911 H. G. Chatain and I were instructed by the General Electric Co. to go abroad and study the Diesel engine situation; we canvassed all Europe. The instructions were to produce as light an engine as possible, with not necessarily light materials, suitable for traction purposes or for vessels as electric generating units or as small stationary sets. We selected a type generally known as the Junkers, and produced a 150-kw. engine which weighs 90 to 100 lb. per horsepower as a stationary set and runs at 500 r.p.m. Being of the double-opposed-piston construction, it has absolutely no valves for the working cylinders, the pistons themselves uncovering the ports. We gave a 20 deg. lead to the cranks, so that the exhaust port would close before the scavenging port starts to close. These engines have been running for a number of years at two different stations in the Philippine Islands and in Porto Rico. We use on these engines hydraulically-operated steel plungers for fuel pumps, *without any suction valves whatever*. They are known as variable-zone, but are constant-stroke pumps. The weak part in any pump is the suction valve. The barrel and the sleeve of the pump are of glass-hard steel. The pumps ran for three years and none has been replaced as yet, to our knowledge. There is no packing to watch; governing is very nearly perfect.

ELECTRIC DRIVE

In connection with Mr. Chatain, who is the head of the gas-engineering department of the General Electric Co. in Erie, I have given considerable thought to the question of ship propulsion. We have substantially come to the conclusion that instead of building large, bulky engines which involve a considerable amount of weight, directly connected to the propellers, we shall follow the practice of the marine steam-turbine development, and introduce electric drive between the propeller and the prime movers. We have laid out tentatively the power equipment for a cargo ship requiring 3000 hp. on the propeller. We find that we can put into the space now taken by the steam turbines, disregarding the boilers absolutely, five of the six-cylinder units of the Diesel-type engines referred to and two two-cylinder units for auxiliaries. The latter can be stowed away in any manner desired because the

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electric drive does not force us to place them in any definite position with respect to the propeller-shaft. We can put them crosswise or in whatever position seems best. The idea of having something like thirty cylinders, or double the number of pistons, for transmitting 3000 hp. may look radical at first sight, but when we consider the matter from the viewpoint of manufacturing and replacements those who have built automobile or Liberty engines in quantities know how low production costs can be cut down when a large number of parts are built. In a steam turbine a large number of small elements transmit the motion of steam to the shaft. Suppose, for instance, a machine with a large number of small pistons connected to one crankshaft. That would be an absurdity, but we can accomplish the equivalent by using a number of small, compact electric direct-current units, and couple them in multiple electrically, keeping one in reserve. In case of any trouble we simply cut out one set and still have the others to go on.

MR. VERHEY:—I have heard and thought much about the electric drive. The fact remains that we have 36 cylinders with all their fittings. The merits of this solution seem questionable at present, in view of the fact that we are losing efficiency by this transformation process very much on the order of the burning of fuel under a boiler and losing valuable heat units, which is the reason for the low thermal efficiency of steam installations. The handling facilities of an engine of 3000 hp. can be made very simple and thoroughly reliable, which also holds good for larger units. I consider it possible to build units for direct drive of 3000 to 4000 hp. at 90 to 100 r.p.m., which meet all present demands for cargo carriers. Why, therefore, should we use a transformation process? The manufacture of six cylinders to a unit offers also a chance for cheap production, in addition to the fact that high-speed engines can never show the endurance that can be attained in moderate-speed engines.

We hear statements advising the use of the surrendered German submarine engines and their installation in ships for electric propulsion, but my experience with both high and low-speed engines leads me to state that I cannot believe at present that we should resort to high-speed engines for installation on board ship. Repair bills will run high and a larger crew of electricians and engineers must be carried.

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MR. LEMP:—We have chosen a speed of 500 r.p.m. We saw an engine run this afternoon at 450 r.p.m. and I think that speed was not abnormal. In order to save weight we must increase speed. I believe that 500 r.p.m. is not excessive for a 150 kw. or 750 hp. engine. Quite irrespective of the ease of reversing, a propeller-shaft driven by an electric motor at constant speed has advantages which no reciprocating drive will approach. In a rough seaway, when the propeller comes out of the water, there is no necessity for having an engineer at the throttle or an automatic regulator to take care of this acceleration. It will be taken care of inherently by the very fact that the speed is constant, irrespective of load. This is very important. Our electric drives on battleships have shown that we can place the motor right in the aft part of the vessel; and instead of carrying a long shaft, the motor can be coupled-up short to the propeller, which in itself is an advantage. Regarding the multiplicity of parts in small engines, I feel that this is not such a great objection as it may seem at first glance. When we come to analyze it, we can introduce manufacturing methods which we cannot introduce in large engines. The type of engine to which I have referred has no cylinder heads and valves. The cylinder is simply an open tube with two rows of ports, and has two pistons moving in opposite directions. The scavenging is very good; the engine is simple to maintain.

For comparison, we had the same workmen and shop organization construct a 100 kw. four-cylinder four-cycle Diesel engine, to English drawings, and a 150 kw. two-cylinder two-cycle, opposed-piston-type engine, of our own design. These two were erected side-by-side on the same platform. The weights of the two-cycle engine were considerably less than those of the four-cycle. The noise of the two-cycle engine at 500 r.p.m. was much less than that of the four-cycle at 450 r.p.m., and the operators greatly preferred the two-cycle engine. An engine of this type can run at high speed without much trouble because there is not such a mass of valves. The port openings are easily cared for.

MR. VERHEY:—I must admit that the feature of an opposed-piston-type engine, which does away with cylinder-heads and valves, is well worth considering. I also know that in this case the number of revolutions can be increased without trouble, due to better balance; but high-speed engines will wear more and endurance may be

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a big factor. We have not tried this proposal. Let us say, however, that your proposition has points worthy of consideration, and therefore should not be severely criticized at this time. If you can make these engines endure, they might be successful.

H. A. SMITH:—Will Mr. Lemp tell us whether in making the arrangement for those small units he took into consideration the unstable condition of a vessel and the end-play that might develop from that?

MR. LEMP:—Yes.

MR. WEST:—In connection with the suggestion of small electric-drive engines, I take it that we are referring to commercial engines and not to warships. I am referring to commercial ships only. We have a company whose business it is to operate a considerable fleet of ore ships. In discussing this matter I have had it brought to my attention very forcefully by our steamship operators that in America the supply of engineers for 90 to 100-r.p.m. engines is more plentiful than of engineers for 400-r.p.m. engines. They make a cardinal point of that. They say that we must operate with very bad chiefs, as a rule, because we cannot get better ones; and they seem to think that is one of the governing principles of designing any form of marine prime-mover, that the kind of men that must be employed has a tremendous influence. They would oppose the small high-speed electric drive for that reason. Ordinarily, we refer to tramp commercial ships, and it is hard to obtain engineers who are sufficiently familiar with electricity and the operation of a considerable number of high-speed engines. These are not my own opinions, but things that have been said to me a number of times. I take it that the demand of our fleet operators is similar to that of those who operate the same kind of ships in other lines.

MR. VERHEY:—We realize that this is true to a certain extent; we cannot say that in America we have the men just now. Every country has the same difficulty when it comes to internal-combustion engines. If we cannot rely on our practical men and make them see that they should be willing to grow with the progress of requirements, we will be very badly off, but I cannot believe that we will suffer from that very long. We had also to train turbine engineers, but today we have good men. I for one do not think it is necessary to feel satisfied that the present conditions will always prevail. If it

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were so, we had better step out of the marine business and deliberately leave it to other nations to train men.

A MEMBER:—How does Mr. Lemp figure the cost?

MR. LEMP:—As a manufacturing proposition, with a large number of small and equal parts you can jig up effectively in place of having complicated layouts. Furthermore, the chances of losses by blow-holes, cracked cylinders and defective castings are very much lessened when there is a large production of one size only. As far as the electric drive is concerned, it would not be difficult to get a mechanical efficiency of 90 per cent from engines to propeller. From the maintenance viewpoint, apparatus of that size is much more easily standardized and made interchangeable, so that repairs really mean replacements of parts by spares fitted to gages, in lieu of hand fitting by experienced marine engineers of the old school. From the operating standpoint, reliability is assured by subdivision into a number of units independently operative and easily connected to one common bus, so, while at first glance the proposition looks absurd, when we come to look into it we find that it has advantages from a manufacturing standpoint.

MR. COOKE:—In regard to marine engines, we use slower speeds than is the practice of other manufacturers. That has been our practice also in connection with stationary engines. We have made a very careful investigation of the subject, both here and abroad. In Europe, they tried to bring out the high-speed Diesel engine to take care of the stationary engine business, to match up with the high-speed European generators, but they found that the slower-speed engines were the best. One of our guarantee engineers told us that the small high-speed marine auxiliary engines should not be used. He advised getting, if necessary, a slow-speed stationary engine, even if it were heavier and cost more, because engines of that type do not require as much attention as the small high-speed engines.

MR. LEMP:—One point must not be lost sight of; the thermal efficiency of the Diesel engine when it reaches 150 kw. is already very good. In fact, it is from 28 to 32 per cent on a brake horsepower basis with the two-cycle type. Very little is gained by using large sizes. The efficiency may reach 34 per cent, but as a general proposition the great gain is in the small unit. There is no great proportional saving in the large unit over the smaller one.

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MR. VERHEY:—The statement that there is no great saving in thermal efficiency above 150 kw. is correct, but it will be granted that the mechanical efficiency of high-speed units is considerably lower than in low-speed engines, which is also a factor for consideration, and affects the fuel consumption which will count during years of operation. When we are satisfied that engine units as they are built today are unnecessarily heavy and in some cases lack proper accessibility and handling facilities, when we believe that the last word in engine design toward direct drive has been spoken, there might be ground for argument, but with the interest that the world takes at present in oil-engine production, with so many brains working, we will eventually see that engine units of from 3000 to 5000 hp., such as are in demand for cargo ships, will give us no more trouble than our present steam installations, perhaps less. In fact, a single-cylinder two-cycle engine of 2000 hp. running at 90 r.p.m. was produced and ran on the test stand in Europe. I personally witnessed this in 1914. On the strength of this, I would not be surprised to see that with proper financial backing units of 12,000 hp. could be built, which, for instance, would be sufficient to propel a battleship of the size and speed of our Oklahoma, a twin-screw installation with reciprocating engines. I remain of the opinion that the life of low-speed engines will exceed that of high-speed machinery, but as long as there are so many angles of consideration and we engineers are called upon to solve problems to suit various requirements, I appeal to all engineers in an effort to assist the United States to meet the competition of other nations, even with our handicap of higher cost of production, as we do not lack manufacturing facilities. We should all render our share of the work, no matter what the nature of the problem may be. I also invite the technical office forces in our shipyards, and others now engaged in different lines of marine work, to pay due attention to changes which are sure to occur, so that we may become prepared to meet all problems in the most efficient way. This can also be referred to automotive engineers who have already made such a wonderful showing by practically standardizing the whole automobile industry. Their experience has been of great benefit to those who have specialized in the heavier installations of greater power. Technical men who have made a life study of certain lines should not close their eyes and feel satisfied that the things we have now will

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last; we cannot afford to take such a position in these times of rapid changes. In this way we shall carry America to the front in this comparatively new line of marine propulsion. Encouragement should also be extended by our Government to all concerned to reach a satisfactory solution of the world's fuel problem for the benefit of our nation in general and the permanent existence of our merchant marine.

A MEMBER:—All marine work must be simple. It does very little good to save fuel and lose the ship. I know a man who argued that the Corliss was the most economical steam engine. It was put on a 9-in. compression cylinder, a complete Corliss gear, but they never built another. A marine outfit is complicated enough without adding any further complications; it must be simple. The reason that the marine engine has been so successful is that it is simple. The engines which passed through English hands were simplified before they went to sea. Engineers have enough difficulty without introducing complications.

MR. TAYLOR:—One thing developed in a Diesel drive coupled to a gear. The coupling is a magnetic coupling. I believe they are working very hard on it and expect fine results. Personally I do not see why that should not be an excellent thing. We have had in the United States much trouble with gear drive. A gear might be made to run successfully. We have in the United States today vessels that have run 50,000 or 60,000 miles without the least trouble with their gears. It appears to me that the Diesel engine running through a magnetic coupling would give a simpler drive than the complicated electric drive.

TRAINING ENGINEERS

The question of obtaining engineers is a matter of training them. The American personnel is very quick to learn. In my experience in investigating gear turbine troubles in the service about 80 per cent have been due to inefficient operation, 15 per cent to poor workmanship and 5 per cent to poor design. We have done things today which in my opinion are wrong. We send men to sea with insufficient training. We do not let them see the engines erected in the shops, but put them on our vessels very often a week before they sail. They do not even see the dock trials. I think that the simpler the drive the better, but if we take the personnel we can obtain in this country, put them in the shop where any

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a chance to know the engines we expect to run, we would undoubtedly get better results. The Danish Company's men spend months in their own shops and they send one of their own specialists aboard ship. That is why the company has had such phenomenal success with its vessels. There is no reason this country should not have the same success.

MR. VERHEY:—I think that the training of engineers should be given utmost consideration. We really cannot afford to let things continue in this respect as they have been in many instances during the war emergency.

MR. JACKSON:—We are going to have all the auxiliaries, cargo pumps, engine auxiliaries and electric drive. In the case of the chief engineer in this particular ship we sent him to the shop where the engines were built and he went through with the engines. He was also there during the building of engines of another size, and he has been chief engineer on the boat with the other engines. We have had absolutely no trouble with those engines, showing that the man has been given proper education as to the manufacture and installing of them. We were, however, much troubled with the operation. This particular man we considered an exceptionally good Diesel engineer. He never knew anything about an electric motor or generator. We tried to teach him something about them and could not.

With regard to the space requirement, that is not always the whole thing. It is possible to get a ship which will have more space in it than we can fill with cargo. In such cases the space does not count. It is the saving in dead weight or machinery weight. In the case of the ordinary tanker if we can save fifty feet that will not help as much as 100 tons' saving in weight.

MR. DAVIDS:—Referring to the connecting-rod, at the New York Navy Yard the wrist-pins in Diesel engines continually burned out for lack of oil. The oil failed to pass up the connecting-rod; a ball check was therefore placed in the large or crank end of the connecting-rod, which held a column of oil. This prevented the burning out of the wrist-pins.

MR. VERHEY:—Referring to Fig. 7, such a construction has been used on smaller type connecting-rods than these. For instance, some builders use this method of lubrication on their compressor connecting-rod. In the

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case shown it is only a matter of keeping up sufficient pressure, which depends on the fit of the bearings. If the clearance is too great or if there is a poor fit in one of the bearings, the oil will merely spread and lose its pressure. When we keep a restricted clearance, the pressure builds up in the grooves in the bearing boxes and there is no doubt that the oil will land where we want it; this is done successfully in most merchant-marine Diesel engines. However, the suggestion is good, and in cases where we have not a sufficient supply of oil at hand it will help, because the oil will be accelerated and go up.

A MEMBER:—Were there three auxiliary engines such as are shown in Fig. 8?

MR. VERHEY:—Yes. On the 12,500-ton ship now under construction for the Emergency Fleet Corporation, we have engines of 2250 instead of 1500 i. hp., such as those on the George Washington, on which I made a long trip. We also maintained three sets, which, however, depends on the number of winches we choose to use and the speed at which we want to handle cargo. As a matter of fact that is where the point comes in; Europeans are not up to the point yet where they consider it essential, as Americans do, to take their cargo out in a very short time. It does not amount to so much in dollars and cents to them as it means to us when a ship lies for a number of days in port longer than necessary. As a matter of fact, we have now adopted European-built winches as suggested, on account of the fact that we had no choice in selecting an American-built winch of suitable proportion.

A MEMBER:—How will that 12,500-ton ship be heated?

MR. VERHEY:—It will have a donkey boiler of about 100 sq. ft. heating surface and at about 100 lb. pressure. It will therefore have a steam-heat system, which means that we must install pipes and radiators and that we take chances in the winter that they will freeze. We will have to run our leads on the deck because we seem to lack confidence in the electrical equipment which, however, in my opinion should be as safe as possible, although probably more expensive. At least one company has already installed such an electric equipment.

ELECTRIC HEATING

MR. JACKSON:—We installed electric heating in two small harbor tank ships of 70,000-gal. capacity and found

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it satisfactory. In a large motorship now under construction, we are installing electric heaters in the quarters in the bridge-house and in the forecastle. In the after-quarters we are using hot-water heating. That the entire vessel is not electrically heated is due to lack of generator capacity for maximum load when all heaters and all cargo pumps are working.

MR. VERHEY:—That introduces the subject of electrical capacity. With several auxiliary sets standing idle we can apply current to the system electrically and eliminate all piping. It is the coming method. We wish to get rid of oil. We raise, however, one point that might be of slight advantage at present. In certain instances we desire to heat the fuel oil in cold weather. To do this we carry a steam-heating coil into the elevated tank, but to use it steam must be generated in the donkey boiler, which is a lengthy process. At the same time we would need to modify our practice regarding the auxiliary compressor for high-pressure air which is carried as one of Lloyd's underwriting requirements. This has reference to the 1000-lb. air compressor which is used for starting auxiliary engines in case all other compressed air is lost. This is made steam-driven on the majority of European ships. In that case we would have to install a small oil engine.

MR. HOWELL:—Would the inefficiency of electric heaters be a detriment, in a passenger ship, for instance?

MR. VERHEY:—We realize that the efficiency of electric heaters is not great, but when we come to figure the matter out, from all angles, the fact remains that we have the power there, standing idle during the voyage, so that we might as well use it when weather conditions so require. Regarding passenger ships, I think we can afford to put in an electric heating system. When it comes to the ordinary tramp ship, that is doubtful, but at all events it does away with undesirable steam lines, etc., and makes a cleaner layout.

SCAVENGING AIR COMPRESSOR

MR. HOWELL:—In a two-cycle engine have you experienced any trouble in the scavenging air compressor? When I was with the Lake Co. we had a Sulzer engine built in Switzerland and at 500 r.p.m. we found that the scavenging could be done with a very much smaller

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scavenging compressor, but on account of maneuvering we had to use two 30-in. low-pressure compressors for scavenging, so that those compressors at a high speed put such a load on the engine that we had much trouble in getting the fuel consumption per brake horsepower that was required.

MR. VERHEY:—If we could take that pump away and have it independently driven, making it meet varying conditions, we would do the right thing. As long as we drive direct we must consider being prepared for the worst condition which we may have to meet, but submarine engine designs, to which you probably refer, do not leave many choices, owing to the limited space in the boat. I know that the pumps are of liberal proportion, but we did not find trouble in meeting the fuel guarantee, as the proportions of the working cylinders were ample.

SKANDIA-WERKSPOOR CONSTRUCTION

MR. WEST:—In connection with the Skandia-Werkspoor engine for the U. S. Shipping Board, the exhaust pipe is immediately over the axis of the cylinders. Must a section of the exhaust pipe be taken off to take off the cylinder?

MR. VERHEY:—To take the cylinder head off, we are compelled to take off the liner also. It is inserted in a box. So, to remove a cylinder, one of the sections must be taken away. This is one point which is adopted right along and considered by the Dutch as the only thing to do. They use an exhaust header all the time on top of the cylinder. It does not seem exactly right for the reason that it involves additional weight at the top of the engine. In some engines we get such a critical point of cross vibration that we do not know where it comes from. When the exhaust header is taken away, we do not invite that chance. I think that the Danes see that, because they support the exhaust from the deck, which is good practice in my opinion. In designing these engines the Dutch practice was so typical that there has not been one company that did not fall into the same old troubles.

A MEMBER:—On the Skandia-Werkspoor engine, can the piston be taken out from below?

MR. VERHEY:—Yes, that is a good feature which I believe no other engine has. An extension or skirt on the cylinder is under the box. The rings can be seen

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and checked, and the carbon can be cleaned off when desired. When the cylinder-head can be lifted the whole thing can be taken out; in this case the connecting-rod and the piston-rod can be left in place. The upper flange of the piston-rod is disconnected and the piston is shoved out. A special arrangement is made for this, attached to the columns.

A MEMBER:—Must the piston be disconnected and pulled through? Are telescope tubes provided?

MR. VERHEY:—Yes. I believe that is done by disconnecting several bolts on the flange which is located on a partition. The crankshaft can be taken out by removing part of the columns. Most engines do not have such facilities.

A MEMBER:—Referring to the bed-plate for the 825-hp. Skandia-Werkspoor engine, how is the lower base for the bearing shaft held?

MR. VERHEY:—That is known as a Dutch dowling. It is a difficult piece of work; a special jig has to be made.

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